

ROBOTICS

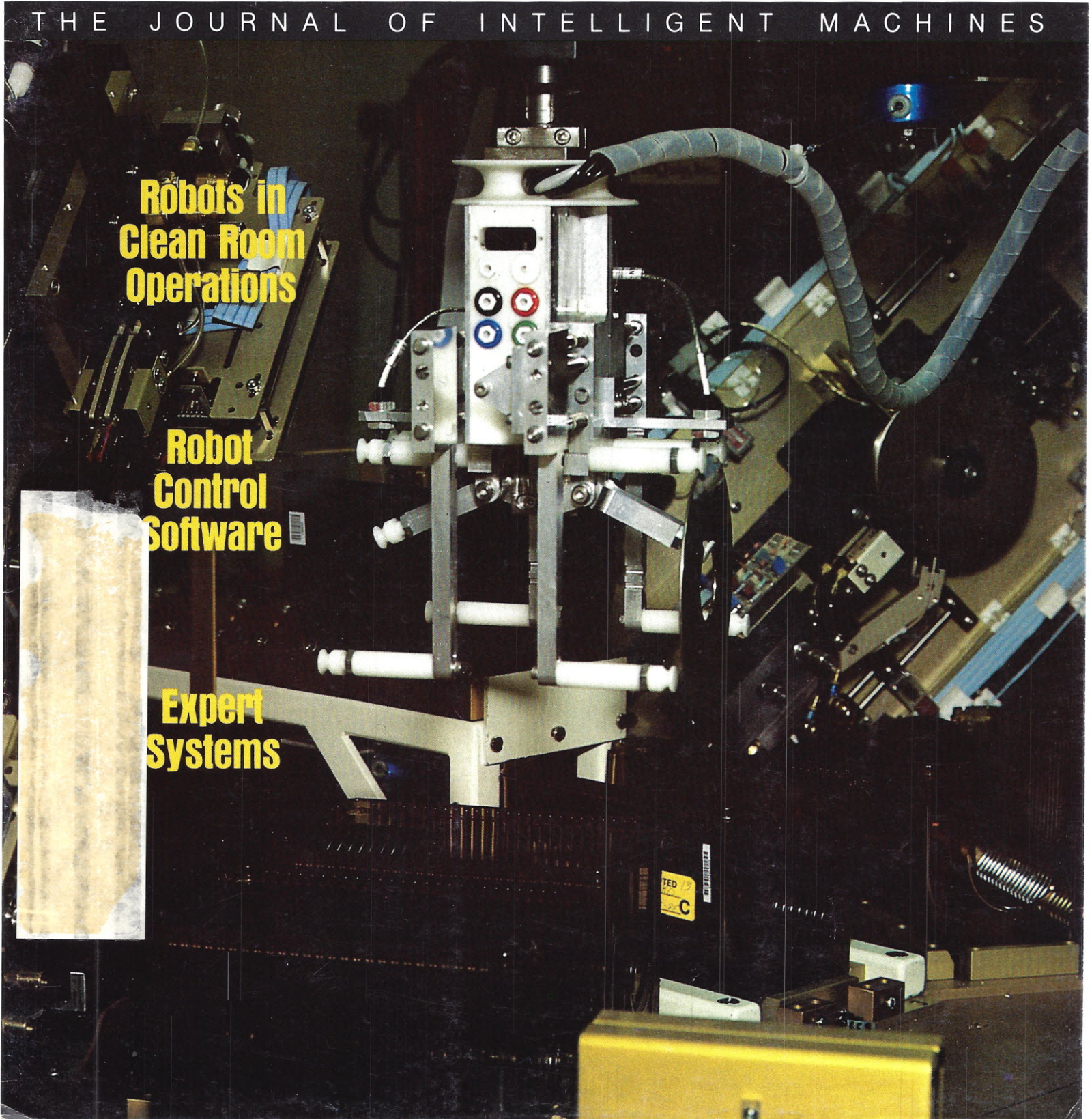
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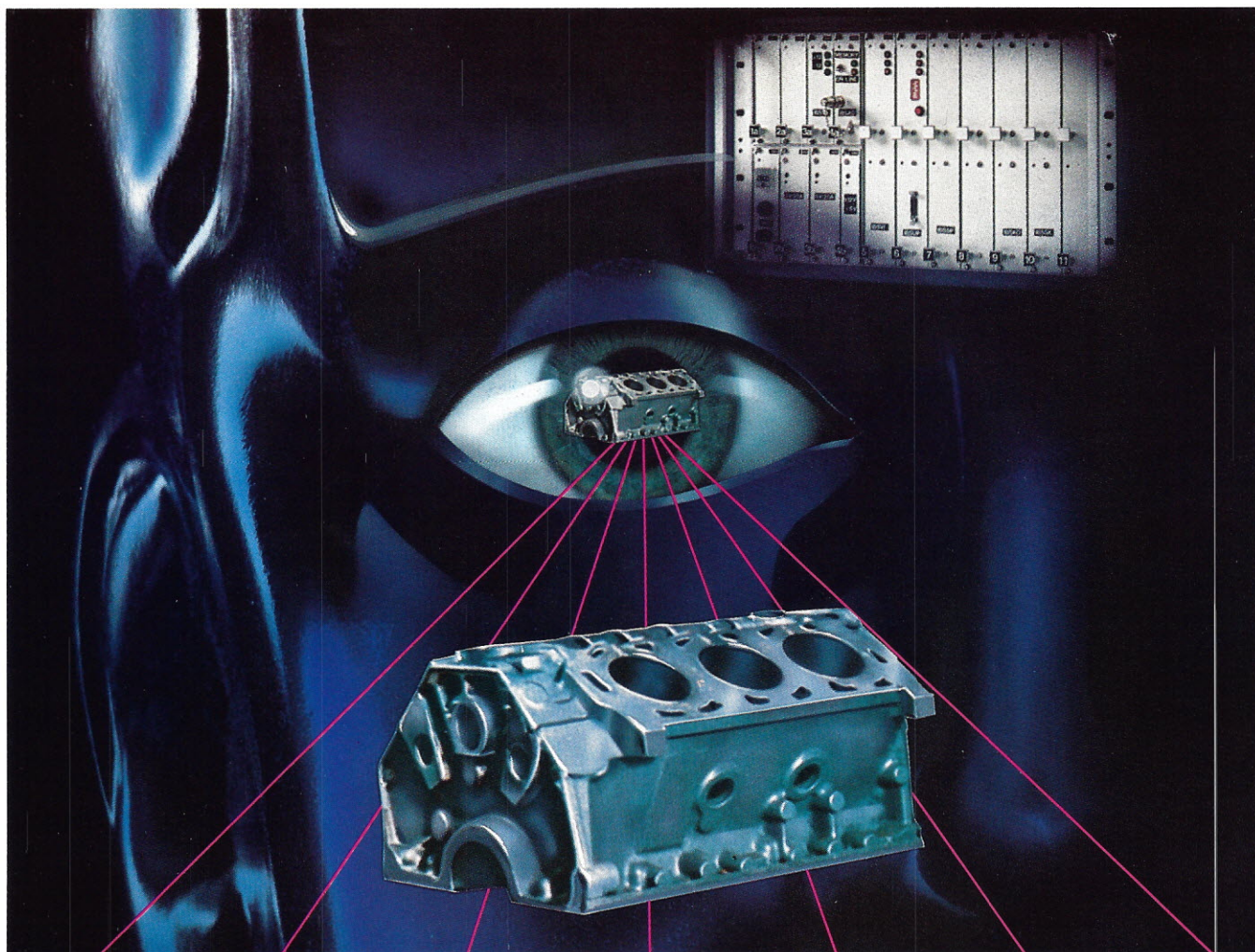
THE JOURNAL OF INTELLIGENT MACHINES

**Robots in
Clean Room
Operations**

**Robot
Control
Software**

**Expert
Systems**





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ENGINEERING

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About the cover: This month's cover photo, provided by Applied Robotic Technologies, Inc. (ART), depicts an IBM 7545 800-S robot adapted for clean room operations. The robot is shown testing rigid disks on a ProQuip certifier. ART's double-sided end effector requires only three seconds or less to remove a tested disk from and place an untested disk onto the certifier spindle. The notched jaws below the end effector move the cassettes along. See related article on page 6.

Editorial

Robotics and Industrial Management

A Guest Editorial by
ERIC MITTELSTADT,
President and CEO
GMF Robotics Corporation
5600 New King Street
Troy, MI 48098

The robotics industry finally is coming of age.

That is to say, our accomplishments in this decade have given our products such wide visibility that they no longer are confused with the humanoids of *Star Wars* and, more important, have resulted in what can reasonably be described as a mature relationship with the customer industries.

When the 1980s began, the general public had little knowledge of what an industrial robot was, or looked like, or actually might be doing in a manufacturing plant. The strongest at-large impression was probably one of concern that whatever it was the robot could do in the workplace, it could do the job so perfectly and at such cost savings that whole battalions of men and women would be displaced from their jobs and turned out onto the street.

While concerns of this sort do not die easily and no doubt still bother some people,

those who are in the best position to know (the "displaceable" workers themselves) have discovered that the reality is otherwise. Rather than losing jobs, automation has saved them by making American plants more productive and competitive and, therefore, better able to stay open. Rather than dehumanizing the workplace, robots, by taking over the simplest, most tedious, dirtiest, and most hazardous jobs, have done the opposite: they have helped employees at the low end of the labor ladder upscale their working lives, moving them to work assignments surely more worthy of human capabilities and aspirations.

When the customer industries—particularly the automotive—turned to the developing robotics industry several years ago, their view

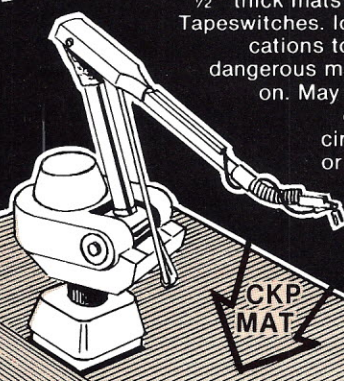
of it was much more sophisticated, of course, than that of the public and their concerns were of a totally different nature. Their concern was that of the businessman who makes a substantial investment in a system he needs to turn his business prospects around and help him bring products to the market on a competitive basis—and then worries that maybe the system isn't good enough after all. If the plant manager, for example, had a concern over the coming of automation to his production line, it was likely to be based on his skepticism about the robots' ability to perform as promised—to weld or seal or paint or unload and load a variety of machines, or move parts and assemblies around as skillfully, dependably, and efficiently as his employees could do it.

The customer industries, in short, had to be shown. And wanted to be shown. And nothing was more important to the developing relationship between them and the

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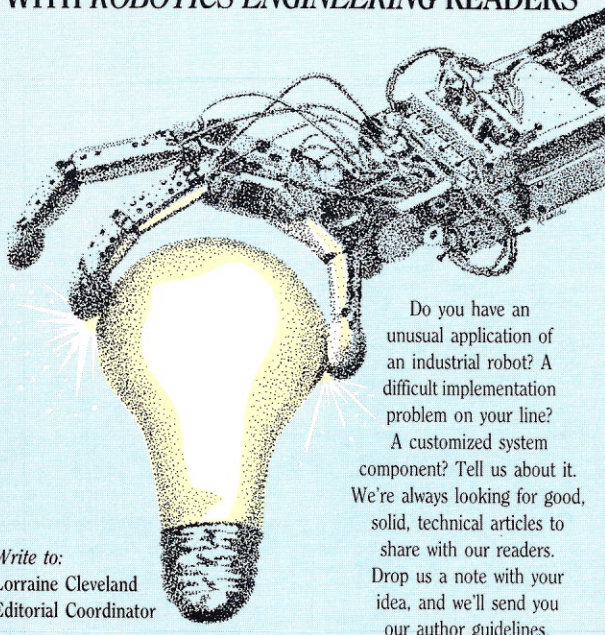
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automation industry—the high-tech suppliers of flexible automation systems—than proving the capabilities of robotic products on the factory floor. This was, after all, the whole point. If the automation systems could not prove their value there, and at once, that might be the ball game. And the World Series.

In recent weeks, major newspaper stories in Detroit have revealed that domestic automotive manufacturers have made considerable headway in cost efficiencies, and in some small-car categories are threatening to wrest price leadership from the Japanese. As manufacturers have seen that the robotics industry contributes to their competitive objectives, their relationships with the robotics companies have matured. Along with this maturation have come increasing respect and support and a better willingness to take the robotics company into a kind of working partnership. This is particularly important to our future and theirs—for the automation industry is primarily a *solutions* industry; the key function of the application engineering resources provided by the industry is to help the end user solve his production line problems. But this can work successfully only if the end user gives the robotics company's application engineering talent a chance to prove what it can do.

In summary, let it be said that most robotics companies today want to be considered not just as a supplier, but as a full and respected partner in the customer's plans to increase the productivity of his plants and the quality of his products.

I think the robotics industry accepts its responsibilities in this relationship. We must be able to understand the customer's production problems and to understand them in specific terms. We must be qualified to recommend a solution and to provide the automation system(s) to create that solution, if this serves the customer's need (and we must never suggest a solution that does not serve the customer's need, even if this results in advising him to stick with the "hard" automation process he is currently using). We must plan to maintain our usefulness for as far ahead as the customer can see, by moving on with our technologies and by providing products ever more talented in their skills and versatility. We must always be alert to ways of finding and marketing new robotic solutions, so that we can continue to help manufacturers become more productive and more competitive with the labor-intensive nations of the world. For the customer's part, it is our hope that he will continue to envision the kinds of technologies that will be flourishing in the 1990s, and that he will be willing and able to implement this vision in time to re-secure our manufacturing position worldwide.

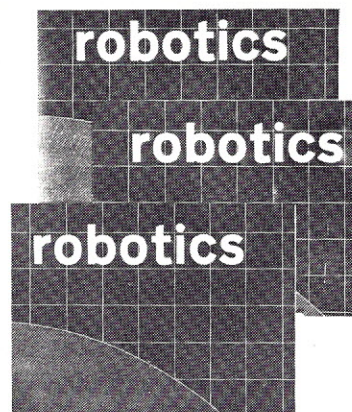
Of course, this is a shared responsibility. The customers depend on us to develop

robotics products and systems for use now and which will be compatible with the technologically advanced manufacturing systems developed for the industrial survivors of the 20th century. We hope that as we honor our responsibility to understand the customer's plant systems, to serve him more effectively, he will educate himself to understand ours—so that when our automation products are wedded to his systems they can work in concert as they are designed to do. We hope that management will understand also that for the robotics industry to serve end users well, now and in the future, with products, innovations, flexible systems, and full support, the V.P. must acknowledge the importance of the supplier's being financially able to commit the necessary resources to those ends.

The historic effort of American industry (again, the automotive industry in particular) to regain a solid competitive footing in global economic give-and-take is well known, and it is ongoing history. The dimensions and complexity of the effort involved all segments of the industrial enterprise: management, union leadership and workers, suppliers—all had their parts to play in the struggle. The robotics segment was the newest player in the game—and to that extent probably inspired the least certitude among the other participants, particularly, it may be assumed, among the various levels of industrial management. The robotics industry can be credited for having held up its end very well indeed. It has justified the confidence of industrial managers who believed it *could* do the job in the plants, and it has (we believe and hope) eased the concerns of those who had some doubts.

The job, of course, was to improve productivity and quality, to make the customer (and the country) more cost efficient. The purpose was, and is, to help bring industrial leadership back to where it belongs. And while major manufacturers might not yet be speaking statistically of those increases in productivity and quality, their plans to continue and expand their uses of flexible automation systems speak for them. In short, the robotics supplier needs to be profitable if he is to be an effective partner.

The robotics industry is, at this time, the most exciting industry in the world because there's so much that we not only *can* do, but *must* do to ensure that U.S. manufacturers realize a better destiny than that reserved for second-rate economic powers. We are, I think, at a stage now where the right relationship of confidence and trust between us is becoming a mutually rewarding reality. Each of us—industrial manager and robotics supplier—must be able to understand the other's problems and goals, and must know what has to be done to secure our future. If we do not, there may be no old age for either of us. ■



Reporting on International Trends in Applications and Business

Editor-in-Chief:

T.M. KNASEL, Vice President and General Manager, Automated Systems Division, MK-Ferguson Company, Cleveland, OH 44114, USA

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ROBOTICS is an international journal carrying thoroughly refereed, up-to-the-minute articles on the practical applications of robotics and related business and technology trends.

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Calendar

MAY

5-6. **Artificial Intelligence: Into the Mainstream.** Stamford, CT. Contact: Mimi Ford, Gartner Group, telephone (203) 964-0096.

6-8. **Control Expo 86.** O'Hare Exposition Center, Rosemont, IL. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

6-8. **Logistex 86.** Cervantes Convention Center, St. Louis, MO. Contact: Logistex 86, 940 Western Ave., Pittsburgh, PA 15233, telephone (412) 323-1808.

7-9. **Applying Machine Vision to the Packaging Process: A Hands-on Clinic.** Itasca, IL. Contact: Joanne Rogers, Special Programs Division, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 399.

8. **The Impact of Artificial Intelligence on Business.** Loews Summit, New York, NY. Contact: Kathy Shaw, Office of Continuing Education, Worcester Polytechnic Institute, Worcester, MA 01609, telephone (617) 793-5517. (To be repeated 5 June at The Marriott, Worcester, MA.)

12-13. **UNIX Operating System Seminar.** Dallas, TX. Contact: Conference Manager, U.S. Professional Development Institute, 1620 Elton Rd., Silver Spring, MD 20903, telephone (301) 445-4400. (To be repeated 19-20 May in Boston, MA; 2-3 June in Washington, DC; 9-10 June in San Francisco, CA; 16-17 June in New York, NY; and 23-24 June in Chicago, IL.)

13. **Computer Integrated Manufacturing: A Productivity Solution.** The Marriott O'Hare, Chicago, IL. Contact: Kathy Shaw, Office of Continuing Education, Worcester Polytechnic Institute, Worcester, MA 01609, telephone (617)

793-5517. (To be repeated 6 June at The Marriott, Worcester, MA.)

13-14. **Machine Vision: Optics and Lighting.** St. Louis, MO. Contact: Joanne Rogers, Special Programs Division, Society of Manufacturing Engineers, One SME Dr., Dearborn, MI 48121, telephone (313) 271-1500, ext. 399.

13-15. **Electro/86 High Technology Electronics Exhibition and Convention.** Bayside Exposition Center, World Trade Center, Boston, MA. Contact: J. Fossler, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045, telephone (213) 772-2965.

14-16. **C Programming Seminar.** Dallas, TX. Contact: Conference Manager, U.S. Professional Development Institute, 1620 Elton Rd., Silver Spring, MD 20903, telephone (301) 445-4400. (To be repeated 21-23 May in Boston, MA; 4-6 June in Washington, DC; 11-13 June in San Francisco, CA; 18-20 June in New York, NY; and 25-27 June in Chicago, IL.)

14-16. **Fiber Optics Technology for Communications.** Contact: Ron Donais, The George Washington University, Washington, DC 20052, telephone (202) 676-8523 or (800) 424-9773.

15. **Flexible Manufacturing Systems (FMS).** The Marriott O'Hare, Chicago, IL. Contact: Kathy Shaw, Office of Continuing Education, Worcester Polytechnic Institute, Worcester, MA 01609, telephone (617) 793-5517. (To be repeated 12 June at the Worcester Polytechnic Institute Campus, Worcester, MA.)

19-22. **1986 International Tool and Manufacturing Engineering Conference and Exposition.** Philadelphia Civic Center, Philadelphia, PA. Contact: Public Relations Department, Society of Manufacturing Engineers, One SME Dr.,

PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

JUNE

2-5. **VISION '86.** Cobo Hall, Detroit, MI. Contact: VISION '86 Public Relations, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

5-6. **Second Annual Workshop on Robotics and Expert Systems/ROBEXS'86.** Gilruth Center NASA/Johnson Space Center, Houston, TX. Contact: Deborah A. Poor, Instrument Society of America, 67 Alexander Dr., PO Box 12277, Research Triangle Park, NC 27709, telephone (919) 549-8411.

9-14. **Advanced Problems in Equipment Maintenance.** Bowling Green State University, Bowling Green, OH. Contact: Dr. Richard A. Kruppa, Director, College of Technology, Bowling Green State University, Bowling Green, OH 43403, telephone (419) 372-2439.

17-18. **Robotic End Effectors: Design and Applications.** Detroit, MI. Contact: Diane M. Korona, Program Administrator, Special Programs Division, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0039.

24-26. **Advanced Manufacturing Systems.** McCormick Place, Chicago, IL. Contact: Cahners Exposition Group, 1350 E. Touhy Ave., PO Box 5060, Des Plaines, IL 60017-5060, telephone (312) 299-9311.

25-27. **Twin Cities Tool & Manufacturing Engineering Conference and Exposition.** St. Paul Civic Center Arena, St. Paul, MN. Contact: Public Relations Department, Society of Manufacturing Engineers, One SME Dr., Dear-

born, MI 48121, telephone (313) 271-0777.

25-28. **CAD and Robotics in Architecture and Construction.** Contact: Viviane Bernadac, International Institute of Robotics and Artificial Intelligence of Marseille/CMCI, 2, Rue Henri Barbusse, 13241 Marseille CEDEX 1, France, telephone (91) 91.36.72.

27. **Flexible Manufacturing Systems Workcell Workshop.** St. Paul Civic Center, St. Paul, MN. Contact: Society of Manufacturing Engineers, Technical Activities Dept., PO Box 930, One SME Dr., Dearborn, MI 48121, telephone (313) 271-1080.

JULY

14-18. **Computer Vision and Image Processing.** Chrysler Center for Continuing Engineering Education, University of Michigan, Ann Arbor, MI. Contact: Engineering Summer Conferences, 200 Chrysler Center-North Campus, The University of Michigan, Ann Arbor, MI 48109, telephone (313) 764-8490.

AUGUST

18-22. **13th Annual Conference on Computer Graphics and Interactive Techniques.** Dallas Convention Center, Dallas, TX. Contact: SIGGRAPH '86, Conference Management, 111 East Wacker Dr., #600, Chicago, IL 60601, telephone (312) 644-6610.

20-22. **Applying Machine Vision to Your Manufacturing Process: A Hands-on Workshop.** Cambridge, MA. Contact: Joanne Rogers, Special Programs Division, Society of Manufacturing Engineers, One SME Dr., Dearborn, MI 48121, telephone (313) 271-0039. (To be repeated 25-27 August in Cambridge, MA, 10-12 September in Minneapolis, MN, and 15-17 September in Minneapolis, MN.)

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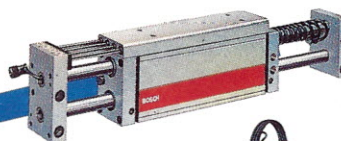
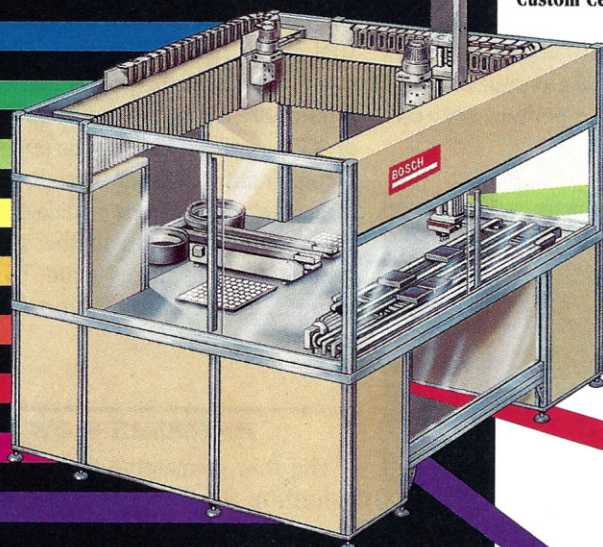
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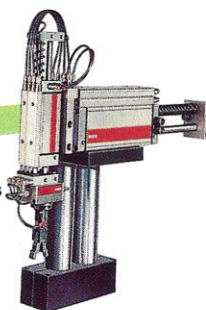
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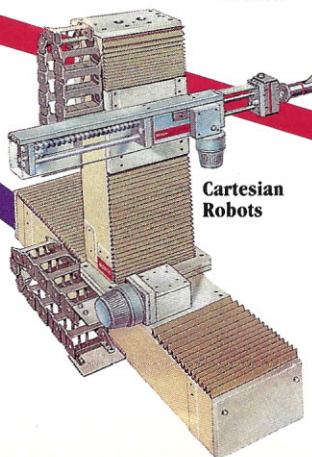
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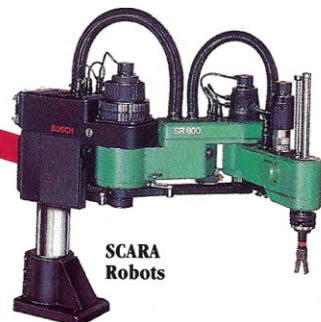
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Cartesian
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Solving Disk Problem Robotic

Ted Lane
and
Neil Brumberger
Applied Robotic Technologies, Inc.
140 J Mason Circle
Concord, CA 94520

Testing is typically the last process performed on a rigid disk before it is installed in a disk drive. Defects and errors in-

roduced during the testing process are usually detected only after the disk is installed; the cost of mistakes is therefore many times that of the disk itself. Simple timing studies sometimes indicate that automated disk certification does not increase overall throughput. Experience, however, makes it clear that human output is not constant. Although human inspectors often match the output of automated systems for short periods, over the

course of time the consistent work of robotic systems pays off in increased quality control.

The DC Series disk certification workcell (Photo 1) was developed for automated burnishing, glide testing, and certifying of 5-1/4 in. and 3-1/2 in. rigid disks. Cell components are an Intelledex Model 605 or IBM Model 7545-800S robot with an Applied Robotic Technologies end effector, Fluoroware cassettes, and an IBM/PC XT or AT controller. The robotic arm services a combination of from three to five burnishers and/or certifiers; a guideway system presents the cassettes to the arm. Burnishing typically takes from 15 to 60 seconds, and certification from 60 to 120 seconds.

MATERIALS FLOW

The flow of material through the cell consists of two primary streams, disks and cassettes, and employs A.R.T.'s double-sided end effector for speed and efficiency. On cell startup the robot picks an

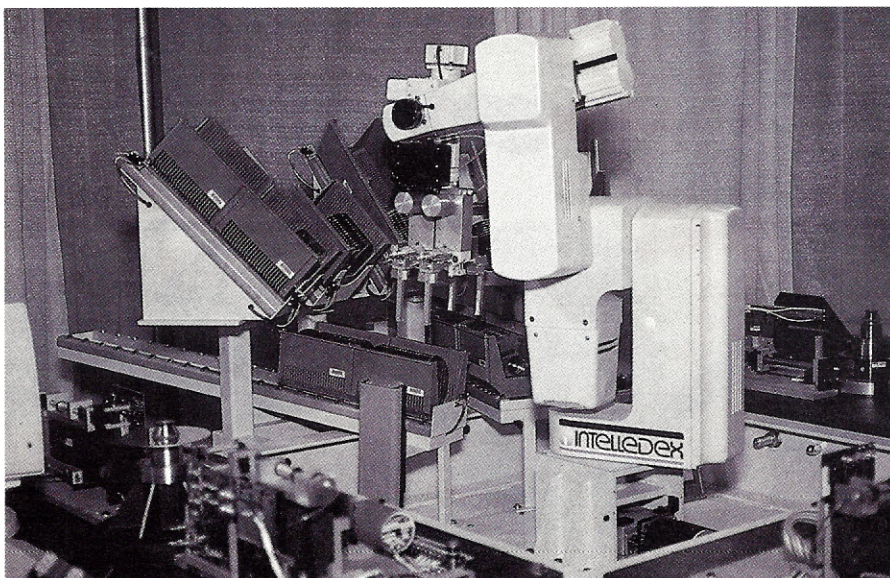


Photo 1. The DC Series disk certification workcell consists of an Intelledex Model 605 or IBM Model 7545-800S robot with an Applied Robotic Technologies end effector, Fluoroware cassettes, and an IBM/PC AT or XT controller.

Certification s with a Workcell

untested disk out of a cassette in the delivery guideway, places it on the spindle of the first certifier, and initiates testing. It repeats the operation for the remaining certifiers. When disks have been positioned on all the certifiers, the control program uses an adaptive algorithm to predict which certifier is most likely to become available first and takes another disk from the delivery cassette to that certifier.

When a certifier has completed its testing, it signals its availability and provides test results to the control program. The robot then services that certifier by picking up the tested disk with one set of jaws on its end effector and replacing it with an untested disk, using the other set of jaws. The robot places the tested disk in the appropriate grading cassette according to the information communicated by the certifier, takes another untested disk from the cassette, and services the next certifier. The double-sided end effector reduces the amount of dead time per certifier between tests. As cassettes of

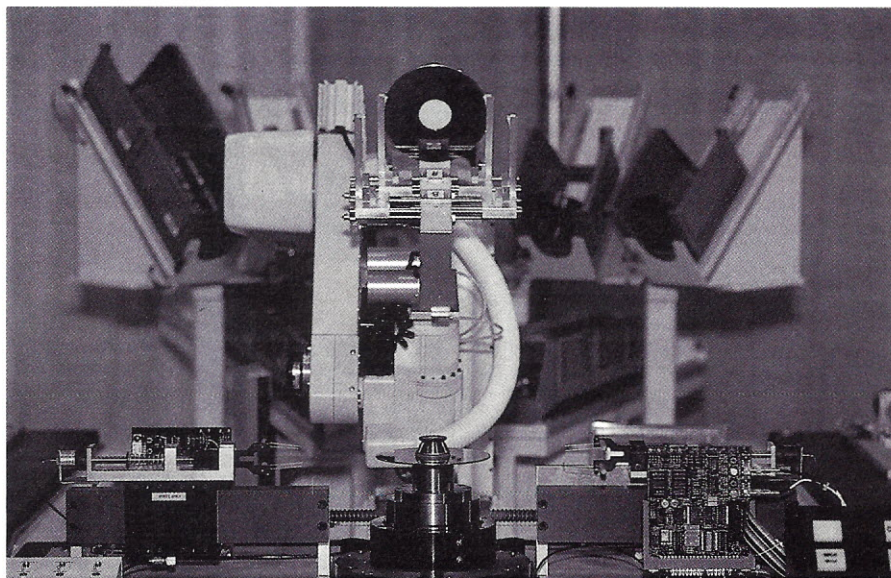
untested disks are emptied, the robot removes them from the input guideway and puts them into one of the grading guideways. As the grading cassettes are filled, the robot puts them onto the removal guideway, thus controlling the flow of both disks and cassettes through the workcell.

Delivery of untested disks and removal of graded disks is required approximately once per hour. The cell is able to handle two different types of cassettes, one for

delivery and one for grading and shipment. Using high-speed serial communications channels, the robot controls the sequence of each tester and captures all the test results for each disk. Based on the test results, the robot places each disk into one of up to 16 different grading cassettes (Photo 2).

An integrated bar code reader allows the robot control computer to identify the serial number of each cassette as it is presented to the workcell, trace the flow

Photo 2. The double-sided end effector uses one set of grippers to place an untested disk onto the spindle and the other set to place a tested disk into a removal cassette. The end effector also provides the ability to move the cassettes through the workcell.



of disks and cassettes throughout the workcell, and provide timely and comprehensive production data. The reader reports the identity of each incoming cassette to the controller, and as disks are tested and graded the complete test history can be captured and retained in a database for off-line analysis and reporting. The database contains the incoming cassette number and slot number for each disk, the time of its testing, the burnisher or certifier on which it was tested, the serial number and slot number of the grading cassette in which it was placed, and the complete test results.

THE END EFFECTOR

Each of the two sets of jaws contains an infrared sensor that senses the edge of a disk. When the end effector is positioned to pick up a disk from either a cassette or a certifier spindle, the sensor indicates whether the disk is actually present before the end effector attempts to grasp it. This arrangement gives the robot (when it is working out of a cassette) the ability to search for disks irregularly placed within a partially filled cassette. The robot can

The cost of defects and errors introduced during the testing process is many times that of the disk itself.

also verify that a certifier spindle is clear before trying to load a disk onto it.

THE OPERATOR INTERFACE

The operator interfaces with the robotic system via the host computer, using a keyboard and CRT for cell startup and shutdown, notification and response processing of operator attention (OA) conditions, and reporting cell production. An OA occurs whenever the control program detects a need for human intervention or assistance. If the supply of untested disks is exhausted, for example, an OA is generated requesting that a delivery guideway

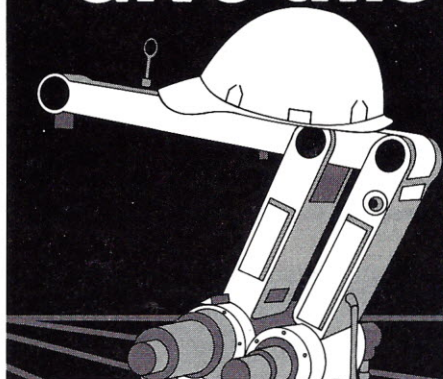
be loaded with more cassettes. If a disk is left on a certifier after routine maintenance, the OA asks that the disk be removed since it might not necessarily be a production disk.

Production is reported on the CRT for all cassettes in the workcell and for all production during the current and the previous three shifts. Production statistics include analyses of product yield and grading distribution by shift, cassette, and certifier. A printer provided with the host computer allows this information to be recorded in hard copy form. A production log is maintained on a diskette for each disk processed; the log contains the source cassette serial number and the slot number of each disk, the data and time of testing, the certifier it was tested on, the disk grade, the grading cassette's serial number and slot number of the disk, and a summary of critical test results as reported by the certifier. The host computer's CRT can also produce graphic displays of cell production and yields.

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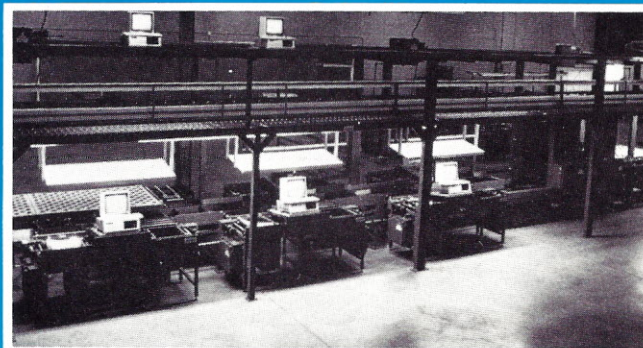
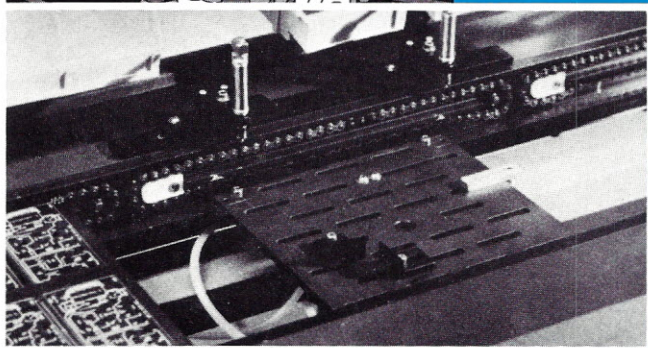


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can also be included in the workcell. If the tester has an automatic recalibration capability, the robot can place a calibration disk on the spindle and initiate recalibration, either at periodic intervals or by operator request. The workcell also keeps track of the yield from each cassette and certifier and can be programmed to detect abrupt changes in yield and to determine if the problem is with a specific cassette or certifier and alert the operator accordingly.

Many production facilities are installing factory-level management computer systems to provide data collection and reporting capabilities for all stages of manufacturing. The workcell host computer can support high-speed communications to such a system and report detailed information on the testing of each disk processed as well as summary information of overall workcell production. The workcell control program includes the following capabilities and specifications:

- It incorporates the disk and cassette flow, dictated by the grading bins and delivery and removal guideways.
- It minimizes the communication time-out delays and provides an efficient way for the robot to poll the status of each certifier.
- It allows any tester to be taken off line or to E-stop without affecting production by the rest of the cell. Once the condition has been corrected, the certifier can be put back on line without interrupting production. When this procedure is carried out, the robot will confirm that a disk is in place on the certifier spindle and will retest it. If no disk is present, the robot will put an untested disk on the spindle to initiate testing.
- A binning algorithm will use the data grade, servo grade, parametric results, and autofail status as reported by the certifier to determine the appropriate bin for each tested disk.

THE HOST COMPUTER PROGRAM

This program includes a boat summary display that shows the count and percent yield by bin for each source cassette number for the current shift. The display includes the cell ID, the time and date the cassette's testing was completed, the total number of disks in the cassette, and the arithmetic averages for the amplitude, resolution, and overwrite parametrics for

the upper and lower surfaces of all disks. This data is displayed in chronological order, and the operator can scroll forward and backward through the list and select a cassette number for display.

A certifier calibration menu allows the operator to monitor and modify the calibration cycle on each certifier. The menu displays the calibration interval for the workcell and the number of disks until the next calibration for each certifier.

Also included in the program is a product binning menu that allows the operator to review and modify the values used by the binning algorithm in the workcell. When the workcell is started up, the operator indicates the name of the specific product binning data file to be used; the program then downloads the binning parameters to the workcell as required. This menu contains a table for determining the product bin, based on the autofail character. One bin can be specified for each non-zero autofail character. A second table establishes the parametric values used to determine the parametric grade. It contains four columns, one for each grade, and five rows, one for each value. A third table determines the product bin, based on the combined parametric grade and defect grade. It contains four columns, one for each parametric grade, and up to 25 rows, one for each data grade and servo grade combination.

USER BENEFITS

The DC Series disk certification workcell offers significant advantages over manual processes. The most important are these:

- Virtual elimination of human handling damage. Human handling damages up to 25 percent of production output, a problem overcome by automated burnishing and certification.
- Consistent product quality. Over the course of time, robotic output is more consistent than that of humans.

Table 1
Manual vs Automated Disk Testing

	Manual		Automated	
	Yield	Output	Yield	Output
Package/Ship	95%	50,000	98%	50,000
Certify	75%	52,631	85%	51,020
Burnish	80%	70,175	90%	60,024
Starts Required	---	87,719	---	66,693

- Reliable, trouble-free operation. The DC Series uses simple, production-proven hardware that requires little maintenance and that is designed for 24-hour-per-day continuous operation. Minor maintenance and inspection of testers and certifiers can be performed without interrupting the workcell's production.

- Compact, modular design. The cell allows the addition or reduction of testers and grading positions without cell redesigns or system downtime. The entire workcell, including four testers, occupies less than 75 ft² of floor space.

- Lower production cost. Reliable, high-volume production, consistent product quality, and reduced handling damage all contribute to lowering the overall manufacturing cost of rigid disks.

Table 1 illustrates some of the benefits of automation.

SUMMARY

Some manufacturers have gone offshore to reduce labor costs only to find that increased inventory and additional freight costs and duty plus the labor and currency stability in a foreign country can offset the anticipated savings. Robotics addresses the problem of high labor costs and offers the additional advantages of rapid local response to technical issues and potentially greater savings through improved quality and yield.

Ted Lane is President and Neil Brumberger is Vice President of Applied Robotic Technologies, Inc.

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Modula-2 as a Language for Robotic Applications

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SMR Associates

PO Box 8028A

Colorado Springs, CO 80933

Table 1
The Robot Abstraction: objects

The robot abstraction consists of the objects that are a part of any robotics system and the operations that can be performed by or on those objects. The objects will be represented by data abstractions and the operations will be represented by process abstractions. Binding of objects and operations is an essential step in the robot abstraction definition.

Objects

1. Sources a. Optical Illuminator b. Laser c. Active End Effector -spray painter -welder -vacuum gripper -machining tool d. Acoustic Voice Box e. Communicator f. Microwave g. Other	2. Sensors a. Passive Imaging Sensor b. Active Imaging Sensor c. Passive Acoustic Sensor d. Acoustic Ranging Sensor e. Optical Ranging Sensor f. Tactile Array g. Force/Torque Sensor h. Accelerometer i. Limit Switch j. Microwave Sensor k. Microwave Imager l. Inertial m. Communicator	3. Mechanical a. Robot Body/Base b. Head/Sensor Platform c. Arm(s) -shoulder link -elbow link -wrist link d. End Effector e. Other
4. Processors a. Image Processors -smoothing -sharpening -segmentation -thresholding -registration b. Signal Conditioning c. Coordinate Extraction d. Range Computation e. Control Equations f. Voice Recognition	5. Executive a. Master Sequencer b. Sensor Executive c. Mechanical Executive d. Processor Executive e. Intelligence Executive f. Safety & Failsafe Executive	6. Intelligence a. Pattern Matching b. Decision Logic c. New Conditions Logic d. Instruction Decoder e. Language Parser

A primary factor in the development of intelligent robotic systems is the supporting software. Intelligent software development includes both the intelligent development of software and the development of intelligent software. Modula-2 offers tools and features that enhance both these areas.

SOFTWARE DEVELOPMENT FOR INTELLIGENT ROBOTIC APPLICATIONS

If we are to discuss "intelligent" robotic applications, we need to provide some ground rules for what is meant by intelligence. Intelligence is a human characteristic that has many and varied definitions. Further, it has different connotations that arise from our individual experiences. It is something thought to be inherently good, and having a lot of it is desirable. However, we find it difficult to accurately define and very difficult to measure, and experimental methods for enhancing intelligence have met with limited and questionable success. Even so, we seek to provide artificial intelligence to robotic systems. In order to do this, we must find ways to describe and quantify intelligent features. These intelligent features are then provided to the robotics system in the form of computer software and hardware components. Specifically, the intelligent

robot has the ability to learn, to apply the rules of logic or some other method for making new decisions and testing their validity. The intelligent robot has sophisticated and controllable sensors for gathering information about its environment. The distinguishing feature of the intelligent robot is that it makes its own decisions.

Today's not-so-smart robotic systems are suitable for applications where the motivation is not intelligence but rather economics, safety, productivity, or quality control. There are robotic systems with varying levels of intelligence that require software control. The goal for future robotic systems is to incorporate features so that they will:

- accept natural language instructions
- understand voice input
- have visual discrimination
- be capable of intelligent motion and learning

The distinguishing feature of the intelligent robot is that it makes its own decisions.

- be self-maintaining, and have adaptive computer assisted instruction capabilities

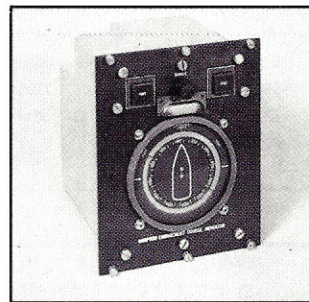
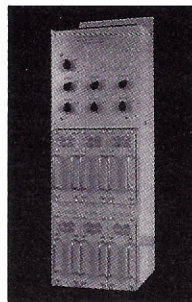
Intelligent software development can be described in terms of two related but distinct methods: the development of intelligent software and the intelligent development of software. The first method includes software components that perform operations resembling intelligent decision making. Typically the methods of artificial intelligence, knowledge representation, expert systems, and knowledge acquisition are used to describe these software components. Although LISP and PROLOG are thought of as the languages used for intelligent software, it is certainly possible to use other languages to implement such software.

The second method is a function of the software developer in specifying, designing, and implementing a particular software system. It implies intelligent applica-

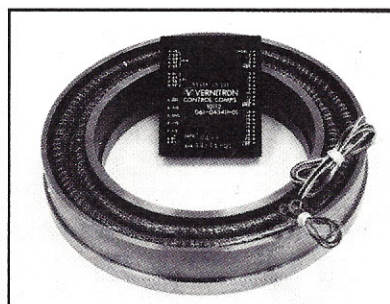
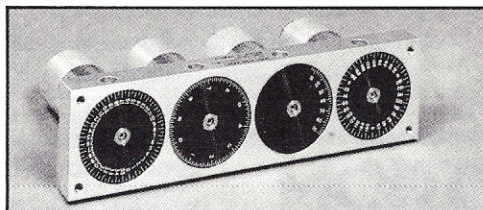
tion of principles and tools, and the success of this method is enhanced if the developer has the means of making the process a more logical, high-level activity that resembles human intelligence.

Historically, the most expensive component of the software life cycle has been maintenance. The initial conception of what a software system should do and how, formulated in the specification and design steps, invariably undergoes many changes during the life of the software. Maintenance includes changing the implementa-

tion details to reflect these new design philosophies. A major problem with many computer languages is that even small changes in one part of the software system can have serious and negative effects on other parts. The maintenance problem is greatly reduced by good software engineering principles such as abstraction, problem decomposition, modularity with carefully protected interfaces, and object-oriented design. Languages that support these principles reduce maintenance costs and increase flexibility for robotic applications.



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Table 2
The Robot Abstraction: operations

1. For each object in the robot abstraction we must define the appropriate operations that can be performed by that object or that can be performed on that object.
2. For each object there will be a number of operations that must be defined.
3. The following is an example of the kinds of operations that may be defined as part of the robot abstraction (for selected objects).

Object: Imaging Sensor	Object: Laser	Object: Arm	Processor: Signal Condition	Executive: Sensor Executive	Intelligence: Decision
Operations a. Freeze Frame b. Transfer Image To c. Change Aperture d. Select Pixel e. Initiate Scan f. Special Features -shading correction -frame average -threshold image	Operations a. Power On b. Set Continuous c. Set Pulse Mode d. Set Pulse Rate e. Initiate Laser f. Pause g. Power Off	Operations a. Get Position of Wrist b. Current Coordinates c. New Coordinates d. Select Motion Type e. Move To New Coordinate f. Move Relative Position	Operations a. Get Signal From Buffer 1 b. Lowpass Filter c. Highpass Filter d. Remove Mean e. Scale Signal f. Remove Noise g. Store in Buffer 2	Operations a. Select Sensor b. Select Command c. Execute Command d. Verify Execution	Operations a. Heuristic Decision b. Minimum Distance c. Best Match d. Bayes Decision e. Neyman-Pearson f. Minimum Error g. S.W.A.G.

DESIRABLE FEATURES OF A ROBOTIC LANGUAGE

The wide variety of the components of a robotic system makes it more difficult to develop a single software environment suitable for general application.

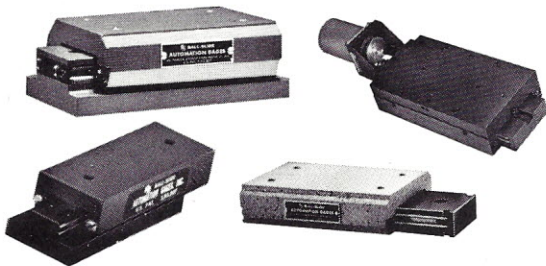
These differences have led to a prolifera-

tion of robot languages: in fact every arm has heretofore had its own control language. As robotic applications become more widespread, standardization should result in a more consistent set of arm movements and control modes. Clearly, a software development environment should be adaptable to such standardization with

minimal maintenance costs.

There are between 16 and 20 specific "robot languages" in existence, with varying feature sets and levels of sophistication (1,2). These languages are in many cases based on either extensions or subsets of existing languages such as Pascal, APL, BASIC, and C. Some of the robot

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languages are low-level, requiring programming on the microprocessor or primitive motion level. Those based on the higher-level languages provide task-oriented commands. The trend in new robot languages seems to be toward block-structured languages—such as JARS (2) and Karel (3)—with commands that have physical meaning to the program developer.

From a review of various articles comparing robot languages it is obvious that there is no clear comparison criterion, nor is there any way to state that one language is always superior to another. Perhaps what is needed more than another robot language is a "software environment" for developing robotic software systems. This software environment should be able to ac-

Perhaps what is needed more than another robot language is a "software environment" for developing robotic software systems.

cess desirable features of a number of languages.

A list of desirable features for a robot control language has been set forth in (1), and can be summarized as follows:

- powerful software development environment
- extensibility for addition of new features
- sufficient and clear constructs
- efficiency
- interaction with I/O devices
- easy access to the computer hardware
- concurrent operation
- clarity, simplicity, and unity of concept
- decision making capabilities
- interaction with the world model of a robot system

Certain features are more valuable than others, in that their very existence provides a mechanism for developing the others. Modula-2 does not include commands for robotic application, but they can be created by the software developer through

"intelligent" designing of the library modules that support the robotic system.

In software engineering terms, when starting with an adequate software development environment it is feasible to define and implement a "robot abstraction" using object-oriented design, top-down methods, and modularity with protected interfaces. Proper design of the modules makes it possible to choose only the data and functional abstractions needed for a particular robotic application. The underlying software environment could be Modula-2 or another high-level environment such as

Ada or UNIX.

Another feature the language should provide is a convenient mechanism for making the transition from off-line software development and testing through hardware simulation to on-line control of actual robotic system hardware. It is unlikely that expensive robotic hardware will be used for software development and testing except as a final step. Most robotic software systems will therefore be developed off-line and tested through simulation. The transition from off-line to on-line should be as smooth as possible.

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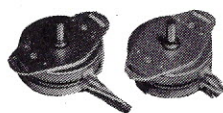
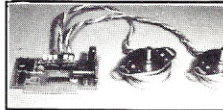
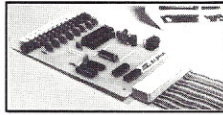
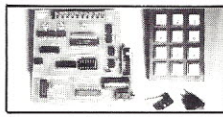
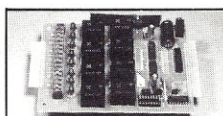
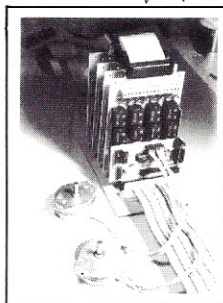
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THE ROBOT ABSTRACTION

Abstraction is a process that allows us to develop very complex software (and hardware) systems at a high level without getting bogged down in implementation details. The development of an informal strategy for the "robot abstraction" and identification of the data abstractions (objects) and functional abstractions (operations on or by those objects) that should be a part of it are the most important tasks of defining a working software development system for robotic applications.

Definition of an informal strategy implies that a specific computer program solution is sought. That is, a particular robotic ap-

plication is being considered. To keep this discussion more general, we will pass over the informal strategy and attempt now to identify a number of objects and actions that would be required to solve a variety of robotics software problems.

Table 1 lists objects that may be part of a general robot abstraction, and Table 2 shows examples of some data abstractions (objects) and corresponding functional abstractions (actions) that could be developed as part of the robot abstraction. Each object could be represented by a separately compilable module as one component of the robotic software system. An applications program would then import only the needed abstractions.

Listing 1 Definition Module for the "RobotArm" Abstraction

```
DEFINITION MODULE RobotArm;

EXPORT QUALIFIED
  (* type *) robotarm, armcoords, motioncode,
  (* proc *) initialize, CalibrateArm, CurrentCoordinates,
              SetCoordinates, SelectMotionType, MoveTo,
              MoveRelative;

TYPE robotarm; (* An opaque type representing the object: robot arm *)
TYPE armcoords; (* Opaque type representing coordinates of arm end *)
TYPE motioncode; (* Opaque type representing various motion modes *)

PROCEDURE initialize
  ( VAR arm : robotarm (* out *) );
(* Sets 'arm' to the device code of the robot arm. Must be called prior to
   any other operation on the robot arm. *)

PROCEDURE CalibrateArm
  ( arm : robotarm (* in *) );
(* Setup procedure for initializing coordinate zero and establishing physical
   parameters for the robot arm. *)

PROCEDURE CurrentCoordinates
  ( arm : robotarm (* in *) )
  : armcoords;
(* Returns coordinates of the robot 'arm' end relative to zero. *)

PROCEDURE SetCoordinates
  ( VAR newcoords : armcoords (* out *) );
(* Returns valid coordinates relative to zero. *)

PROCEDURE SelectMotionType
  ( arm : robotarm (* in *) )
  : motioncode;
(* Returns 'motioncode' from those available for robot 'arm' *)

PROCEDURE MoveTo
  ( arm : robotarm (* in *);
    code : motioncode (* in *);
    newcoords : armcoords (* in *) );
(* Move 'arm' end to position 'newcoords' relative to zero. *)

PROCEDURE MoveRelative
  ( arm : robotarm (* in *);
    code : motioncode (* in *);
    coordshift : armcoords (* in *) );
(* Move end of robot 'arm' by 'coordshift' relative to current position. *)

END RobotArm.
```

Each module in the robot abstraction consists of two parts: an interface definition given by a **definition** module, and implementation details given by an **implementation** module. This separation of the definition and implementation of software components is one of the strongest features of Modula-2. It offers easy extensibility of the language, provides a high-level approach to designing new software components, and provides carefully protected interfaces that minimize fallout effects of changes in a software system.

Additional details on how modules that are part of the robot abstraction are developed and used are given in Listing 1, which defines the objects and operations that are to be a part of the robot arm. Three objects are defined: "robotarm" (the robot arm), "armcoords" (the coordinates of the end of the arm), and "motioncode" (a code that identifies a particular mode of movement available for the specific robot arm). The initialize procedure returns a unique device code for the arm. A software system controlling more than one arm would have different device codes for each. The CalibrateArm procedure allows specification of coordinate zero, coordinate system, and physical parameters for the arm. The remaining functional abstractions require that the device code be an input parameter.

In order to use the abstractions provided by RobotArm, a software developer need only import those features that are to be used. Listing 2 illustrates the use of selected features of RobotArm. Both the definition module for RobotArm and the program module "testarm" are compilable entities. At this point, none of the implementation details for RobotArm are required.

The interface and use of RobotArm are illustrated as independent of the implementation details; the conceptual design can proceed without these details, but they must be provided prior to execution of the test program. In the Modula-2 software environment, neither of the above two modules needs to be recompiled as the implementation details are developed.

The implementation details may include low-level features for convenience and efficiency, as well as the standard high-level constructs that are part of the language. Modules may be implemented in other languages as long as there are adequate hooks into those languages from the

Modula-2 environment. Such hooks exist for machine language and assembly language; they could be added for C or other efficient languages. Additionally, abstractions from library modules may be imported for use by the RobotArm module.

Successful development of a software environment for robotics applications depends in great part on the judicious definition of the software components that should be a part of it. That is, the data and functional abstractions that represent the objects and actions of the robot hardware must be carefully defined. Modula-2 provides an environment for developing intelligent software using intelligent methods.

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Listing 2 Test Program For Abstraction "RobotArm"

```
MODULE testarm;

FROM RobotArm IMPORT
  (* type *) robotarm, armcoords, motioncode,
  (* proc *) initialize, CalibrateArm, CurrentCoordinates,
    SetCoordinates, SelectMotionType, MoveTo,
    MoveRelative;

VAR
  coordinates : armcoords;
  motion      : motioncode;
  thisarm     : robotarm;
  coordshift  : armcoords;

BEGIN
  initialize ( thisarm );
  CalibrateArm ( thisarm );
  SetCoordinates ( coordshift ); (* Specify a coordinate shift *)
  coordinates := CurrentCoordinates ( thisarm );
  motion := SelectMotionType ( thisarm );
  MoveRelative ( thisarm, motion, coordshift );
  (* Move the arm by 'coordshift' relative to current position *)
  MoveTo ( thisarm, motion, coordinates );
  (* Move the arm back to original position *)
END testarm.
```

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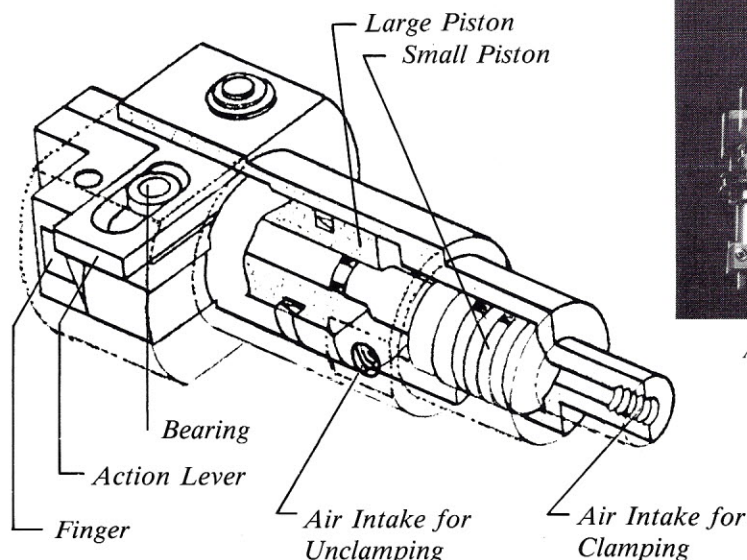
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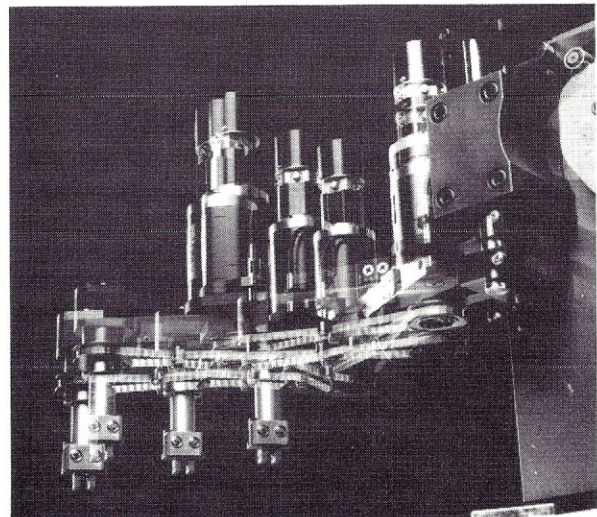
Dr. Pinson is an Associate Professor of Computer Science at the University of Colorado, Colorado Springs, and Senior Partner at Software Microelectronics Robotics Associates, also in Colorado Springs.

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Expert Systems: The Cutting Edge of Artificial Intelligence

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University of Houston—University Park
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The study of artificial intelligence (AI) encompasses an extremely broad range of inquiry. For the most part, however, the public, the press, business, and industry seem to regard expert systems as AI's only manifestation. In an earlier article (*Robotics Engineering*, January 1986) I indicated that AI applications fall into two broad categories: problem solving and decision making systems, and intelligent communication systems. Expert systems fall under the former category, while speech, natural language understanding, and computational vision systems fall into the latter. Expert systems truly represent the cutting edge of AI, for it is to this technology that industry is looking for resolving bottlenecks in manufacturing operations. But more important, expert systems, and AI in general, bring us to the threshold of the next major cycle of productivity gains and can help bring about the "intelligent factories" of the postindustrial society of the future. The current phase of computerization in manufacturing is really a transition phase from the industrial to the postindustrial age.

It is unlikely that there ever will be a universally acceptable definition of AI, but to give coherence to the ideas and topics discussed here I will define AI as **the study and formalization of decision making and problem solving, using symbolic information**. We can regard expert systems as computer programs that use these formalisms to solve or help solve problems in a specific domain at a level comparable to a human expert in the field. The use of symbolic information is essential—we do

not regard high-performance computer programs that compute fast Fourier transforms, statistical packages, and such as expert systems. We now have computer programs that can solve mathematical problems in symbolic form, diagnose diseases, configure computer systems, determine the structure of complex organic compounds, locate faults in telephone cable networks, and perform other similarly skill-demanding tasks. These are representative

of the level of expert systems technology as it is today. Although, it is beyond the scope of this article to attempt an enumeration of even a small fraction of all the expert systems built so far, we have provided a small sampling of them (see sidebar). Waterman's book, (*Guide To Expert Systems*, Addison-Wesley) has very full descriptions of nearly all the expert systems built through 1985.

Several factors should be noted when

Notable Expert Systems Built Through 1985

- DENDRAL is an expert system developed at Stanford University that determines the structure of complex organic compounds based on the chemical formula and data from its mass spectrogram and nuclear magnetic resonance. It is in regular use in many laboratories and has proven a valuable and cost-effective tool. Its performance is on a par with an experienced Ph.D.-level chemist, but much faster.

- MACSYMA was developed at MIT for solving mathematical problems *symbolically*. Its capabilities include the solution of mathematical problems of nearly every kind in physics and engineering. In its particular domain, it has no human peers. It is in widespread use all over the world.

- Prospector was developed by SRI International and has been successfully used in exploration geology.

- DELTA was developed by General Electric Corporation for troubleshooting diesel electric locomotives. This has helped GE save a lot of money by not having to fly its maintenance engineers to all the stations to correct each simple malfunction.

- MYCIN is the first of a series of expert systems built for disease diagnosis. Its domain of expertise is blood infections, in which it can diagnose disorders and prescribe treatments with the help of patient history, test data, and a large knowledge base of specialized rules about infections of the circulatory system. Stanford has rated it on a par with the best diagnosticians in the field. MYCIN has led to a substantial number of similar systems that address other medical conditions; several are in use in hospitals.

- XCON/XSEL was developed by Digital Equipment Corporation and Carnegie-Mellon University to configure and service computers produced by DEC. It is probably the most successful expert system application to date.

looking at expert systems applications. First, most are human-machine systems that provide assistance to human experts in specific, fairly narrow fields. In effect, they amplify the productivity of an expert rather than replace it. This could conceivably change if the nascent AI industry were to acquire the right marketing know-how instead of just trying to produce and sell products with a focus on technology. The AI software companies are at present primarily trying to sell tools and training, rather than full-blown applications; the implicit assumption is that application development and systems integration are the responsibility of the customer. There are some signs of change, however, and we are beginning to see software products addressing specific needs such as financial management.

Expert systems also exhibit specialization by the manner in which they reason or the inference mechanism they use. A diagnostic system like MYCIN typically uses backward chaining, i.e., it reasons back from symptoms to arrive at their causes. A design system such as XCON reasons forward to arrive at its goal, the full configuration of a computer, by piecing together subsystems and components in a manner akin to solving a jigsaw puzzle. DENDRAL is a generate-and-test system that postulates a possible structure and then matches it against actual data for consistency. A monitoring system such as ESCPEM, which will be described later, is a hybrid that monitors the status of a chemical plant by comparing its performance to an internally coded model, diagnoses causes of deviations, and prescribes remedial action. Most expert systems applications today thus can be said to embody one of these "architectures," depending upon the application.

Getting Started. How does one learn to build an expert system, or become a "knowledge engineer," as such people are often called? There is no simple answer to that, since organizations differ widely both in their skill mix and management culture, but I will try to offer some general guidelines. The single most important step is problem selection. Also, it is always best to start on a small scale, using inexpensive hardware and software. The IBM PC and a good version of LISP or even LOGO are adequate choices during the learning phase. It makes sense to acquire a can-

didate list of problems, even if one is not planning to work on all of them, for learning to select suitable applications is a valuable experience in itself. A general rule for problem suitability is that the expertise needed for it must be entirely cognitive and not dependent upon any special intuition and/or sensory gift. Also, such expertise should be teachable to any motivated person. The next step is to try to decide the kind of inference mechanism or the architecture appropriate for the application, after which one can begin to express the problem in the form of **production rules** or **if—, then—** rules.

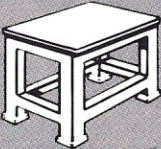
It is extremely important to understand two facts right at the outset: expert system design should be regarded as a systems engineering exercise, rather than one of software development; and the problem chosen should be in a narrow domain. Much of the early AI research was driven by the belief that systems could be designed with a high level of general intelligence and then trained to do any task well. Such systems ended up being too weak. It was only after it was understood that systems, like people, need a great deal of specialized knowledge to reach expert

level performance that really powerful expert systems came about.

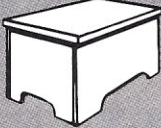
Languages. LISP is popular in the U.S., while PROLOG is popular in Europe and to some extent in Japan. The Japanese made a commitment to use PROLOG in their famous Fifth Generation Computer Project, a choice that in my opinion unwisely limited their options before they had gained enough experience. I do not consider PROLOG a serious competitor to LISP as a general-purpose AI language, although it has its uses for some specialized applications. PROLOG systems are at least a decade behind LISP in maturity; further, it is relatively easy to get PROLOG to run in a LISP system. LOGO is very similar to LISP and can be used to learn to program AI systems, including expert systems. Excellent versions of LOGO are available for PCs, but in the long run LOGO is not a substitute for LISP for serious applications. Another intriguing possibility is that FORTH might turn out to be the dark horse when real-time expert systems begin to be installed, for it seems to have the right constructs for such applications.

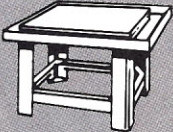
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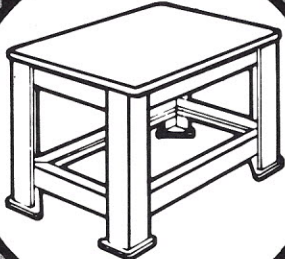
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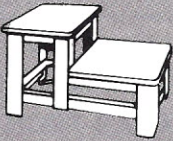












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Before examining expert systems in greater detail, I wish to put forth two developments I expect to see when the use of expert systems becomes widespread. First, there will be significant increases in productivity in discrete parts manufacture, in effect a blurring of the distinction between the discrete and the continuous process industries. Second, there will be a blurring of the distinction between manufacturing and the information-based services industry.

THE STRUCTURE AND ORGANIZATION OF EXPERT SYSTEMS

We will now turn to the organization of expert systems at a fairly high level of abstraction, examining their component subsystems and the tools and engineering methodologies involved in developing their applications. The following is directed to those who do not wish to become involved in the actual design and implementation of specific expert systems applications, but who would like some understanding of the technical underpinnings of such systems. This discussion is of the most basic of systems that can still be called expert, and

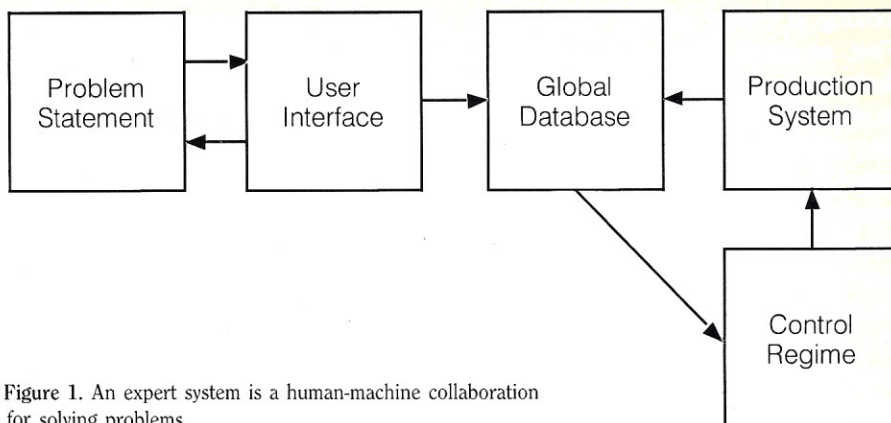


Figure 1. An expert system is a human-machine collaboration for solving problems.

any number of variations are possible.

It is useful first to examine the different functions to be performed. Every expert system begins with a user interface that receives input from the user and provides the user with responses from the system. These responses can be the solutions the user requested, indication of failure to provide such solutions, or requests for additional information from the user. This interface is responsible for communicating with the problem statement as it exists in the outside world and for translating this statement into a form or data structure upon which the problem solving parts of

the expert system can begin to act. Such a form, which is a computer language representation of the problem statement, is often called the "global database." This is an unfortunate use of the term, for global database is correctly used to mean only the statement of the problem as expressed internally in the expert system (Figure 1).

Second, every expert system needs the knowledge required to solve a particular class of problems, a property generally called **domain knowledge** which must be obtained from problem specialists. Since high-level human expertise calls on

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specialized skills and training, it follows that AI systems based on human expertise will also be quite specialized. This collection of rules forms the **knowledge base** of the expert system. Expert systems in which knowledge is represented in the form of production rules are called **production systems**. Production rules are by no means the only formalism available for representing knowledge, although it is the one most widely used. The formalism is not appropriate when the class of problems at hand calls for a heavy dependence on mathematical representations and an algorithmic approach.

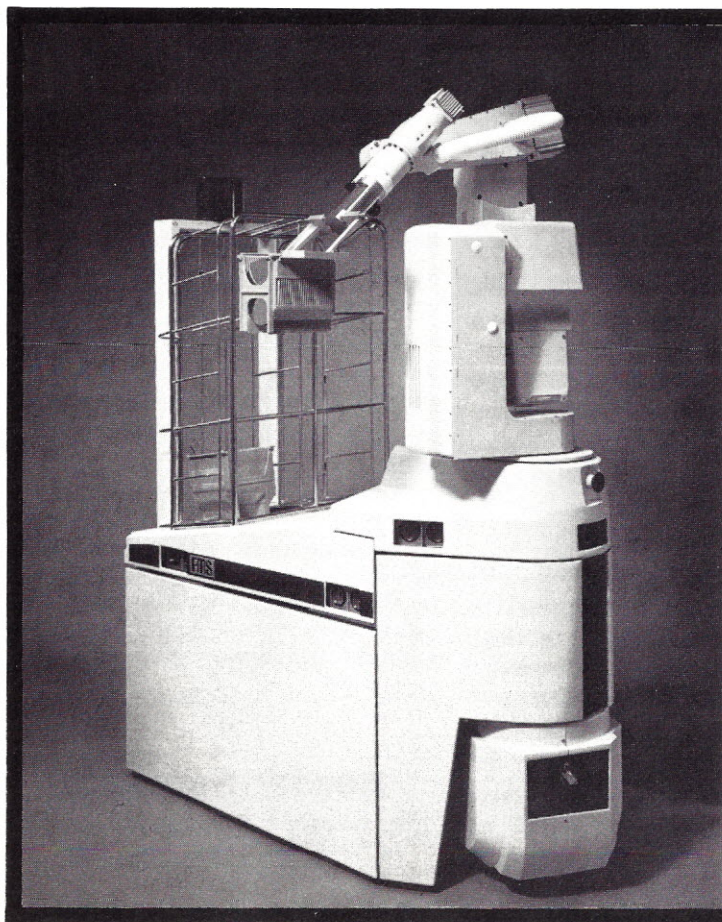
The third component of an expert system is a facility for supervising and providing for the control regime. This is often called the **control system** or the **inference engine** of the expert system, and it has two basic functions. First, it decides whether to go to the user interface and communicate with the user, as was explained earlier. Second, it must decide which rule to apply to the problem next. Since even a moderate sized expert system will have hundreds of rules, rule selection must be based on some strategy and cannot be conducted by blind search. It is often

based on some simple rules of thumb experts have developed through experience, **heuristic knowledge**. In fact, **heuristic programming** is sometimes used as a synonym for expert systems development. The importance of problem-specific methods to high-level expert problem solving led to the development of today's high-performance expert systems. Previous attempts to build systems based on general methods produced relatively weak systems.

Summarizing here, we can say the knowledge base contains **factual knowledge** about the problem in the form of production rules, and the control regime needs the **method knowledge** to function effectively. Two completely different systems can have the same information yet different methods of operation. For instance, a computer aided design (CAD) system might have the knowledge base to design a given product but lack the method knowledge necessary to determine whether the product can be manufactured in a particular plant, even though a manufacturing expert would be able to do this from the CAD data. This lack is a fundamental hindrance to the complete automation of any manufacturing operation.

A CASE STUDY

An examination of ESCPEM (Expert System for Chemical Plant Emergency Management) will serve to illustrate the concepts presented above. ESCPEM was developed by Haile Tsehaie and this writer at the University of Houston to study potential uses of expert systems for improving plant safety. The specific facility was the reforming unit in a hydrotreating and reforming plant. Extending the system to deal with the hydrotreating part would be quite routine, and we felt that no additional insights would be gained in going through with the exercise. The reforming reaction is endothermic and releases hydrogen as a byproduct. The reforming unit reforms the molecular structure of its feedstock from straight chains to cyclic forms, thereby raising the octane number. It is a complex system, containing a potentially explosive mixture of liquid hydrocarbons and hydrogen gas and operating under a severe regime of 40 atmospheres and 500°C. In emergency situations, the operator might be flooded with a stream of alarms that would make it difficult to digest the information, filter out irrelevant



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facts, and take the proper remedial actions. On the other hand, the seriousness of potential hazards makes swift and accurate diagnosis and remedial action absolutely vital.

The following capabilities were deemed essential to ESCPEM:

- It should continuously monitor the plant, detect any deviations from the norm, and alert the operator immediately.
- It should assist the operator in two ways, first by diagnosing the cause of the abnormality and second by corrective action.
- It should shut down the plant in the event of an extreme emergency.

At present, ESCPEM can deal with failures in five systems: feedstock, circulating gas, coolant, fuel system, and instrumentation air.

The knowledge base consists of five modules of production rules, each corresponding to one type of emergency. The modules are supervised by a system that makes a preliminary diagnosis of the nature of the fault and then selects the appropriate module for more detailed investigation and action. Thus, ESCPEM can be regarded as composed of five "specialists" who report to a "supervisor." This architecture reflects the manner in which human experts function and is the principal heuristic used in ESCPEM. The rules are represented as AND/OR trees, and inferences are made by searching the particular rule base to find the rule that matches the reported conditions of the fault. As is the case with most diagnostic systems, inferencing is implemented as a backward searching routine. (These system implementation details are beyond the scope of this article.) ESCPEM was implemented on an IBM PC with 512 Kbytes of memory in a version of COMMON LISP known as GC LISP, but it could just as easily have been done in LOGO.

Each module contains: diagnostic and prescriptive knowledge, both of which are needed in emergency management. Diagnostic knowledge consists of rules for diagnosing abnormalities, whereas prescriptive knowledge is composed of rules for prescribing remedial actions for the diagnosed abnormalities. Clearly, every prescriptive rule has to be preceded by one or more decisions in which diagnostic rules were used. For example, the module responding to feedstock failure has the

An Interactive Session with ESCPEM

Please respond by typing yes or no to the queries.

ESCPEM: IS THE FEEDSTOCK PRESSURE FALLING?

USER: yes

ESCPEM: IS THE FEEDSTOCK PUMP OPERATING?

USER: yes

ESCPEM: IS THE FEEDSTOCK LEVEL DECREASING?

USER: no

ESCPEM: IS THE PRESSURE AT OUTLET LOW?

USER: no

ESCPEM: IS THE COIL SUPPLY LINE GROUNDED?

USER: yes

ESCPEM: * THEN THERE IS REDUCED COIL VOLTAGE *
DID COIL PROTECTION RELAY FAIL TO ACT?

USER: yes

ESCPEM: * MY DIAGNOSIS IS AS FOLLOWS *

* MAGNETIC CONTACT COIL OVERLOAD *

* CAUSE OF CONTACT COIL BURN *

* CAUSE OF PUMP MOTER FAILURE *

* HENCE CAUSE OF FEEDSTOCK FAILURE *

* MY RECOMMENDED ACTION IS—CHANGE COIL *

following rule in its diagnostic knowledge base:

IF feedstock pressure is falling, and the feedstock pump is operating,
THEN feedstock system is malfunctioning.

An example of a prescriptive rule is this:

IF feedstock system has failed, and air bubbles are cause of failure,
THEN switch to gas circulation.

The system has over 100 such rules to assist in its diagnostic and prescriptive tasks and may be called a moderate sized prototype. A sample session with ESCPEM appears above.

The structure and organization here outlined are what I consider the simplest possible program that can be called an expert system. Additional features, such as the ability to explain the reasoning behind a decision and facilities for updating and enhancing the knowledge base, would be included in a more elaborate system. In time they will come out of the laboratory and gain a place as essential components of expert systems in real-world applications.

Dr. Rajaram is Associate Professor in the Department of Industrial Engineering at the University of Houston. He has worked for Lockheed and is a consultant to NASA. His book, *Design of Expert Systems on the Personal Computer*, will be published by Prentice-Hall.

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Starts on page 66

AUTOMATION NEWS

The Newspaper for Flexible Manufacturing November 4, 1985 A Grant Business Publication Vol. 3, No. 14



High Tech Companies Bearing Disproportionate Tax Burden
by Rachelle Jones
WASHINGTON, D.C. — High-tech companies are paying larger-than-average share of income in federal taxes, from 12 to 27 percent higher the average paid by industrial sectors.

According to a Congressional Budget Office (CBO) study, the average, 26 percent income in federal taxes of electronic component manufacturers is 33 percent, and on the average, the rate is 28 percent on the drug industry. By contrast, the average rate on the oil and gas industry is 12 percent, on personal office equipment 13 percent, and on the food industry 23 percent.

The Congressional Budget Office report, released last week, is the first of its kind to compare the tax burden of different industries. It also found that the average rate on the pharmaceutical industry is 27 percent, and on the chemical industry 26 percent.

As for its massive layoffs earlier this year, the company maintains that it is "down-sizing" its manufacturing. Of course, Com-

Computervision Struggling To Regain Market, Cut Losses
by Michael Ball
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A Robot Control System Based on FORTH

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and

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Gaithersburg, MD 20899

For over 10 years, the National Bureau of Standards has conducted research in robotics. NBS has developed a Real-Time Control System (RCS) that uses the sensory-interactive hierarchical control model. RCS has been implemented by a small team of programmers and can control a variety of robots (Photo 1). Suggestions and theories detailing the needs of a fourth-generation robot controller have evolved from the implementation of RCS (1,2).

The goal of the robotics research at NBS has been to use the hierarchical model to establish standardized interfaces between successive levels of the task decomposition and sensory-interactive knowledge building. These interfaces would allow communication among levels to consist of a list of agreed-upon commands and status handshakes. With the goal of standardized interfaces realized, control levels developed by different interests could communicate via this protocol.

In robot hierarchical control, tasks are decomposed into simpler and simpler tasks. Eventually, the tasks are decomposed into low-level control commands for the robot. As the tasks for each level are decomposed, sensory-interactive knowledge building is occurring simultaneously. Low-level sensor information is gathered and combined into higher and higher levels of knowledge about the current state of the robot's environment. This feedback is used by the hierarchical control system to compare the actual state vs the expected state to provide control commands for the next command cycle.

Much of the initial work involved integrating a structured light vision system to work with the control system (3) (Photo 2). Current work has emphasized the goal of integrating robot functions as a part of

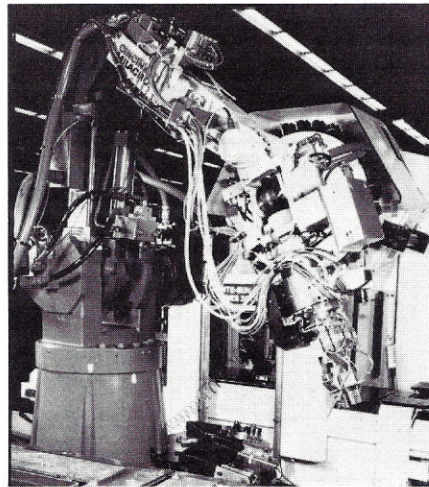


Photo 1. Among the robots in the Automated Manufacturing Research Facility (AMRF) of the National Bureau of Standards is a Cincinnati Milacron T3, used in the horizontal workstation.

an Automated Manufacturing Research Facility (AMRF) (4,5). The AMRF is a demonstration facility developed to serve as a research tool for studying measurements and standards in the automated production of machined parts. The control architecture developed for the AMRF is an extension of the hierarchical robot control system theory. The AMRF has proved that the concepts established by RCS are not limited to robot control systems, but pertain also to a broad body of programming endeavors.

A REAL-TIME CONTROL SYSTEM

The RCS software has been implemented with FORTH as its base coordinating and development system. Any number of programming languages can be used to solve the wide variety of problems associated with robotics, but some are bet-

ter suited than others for certain tasks. Assemblers are best for low-level, high-speed hardware interfaces; block-structured compiled programming languages such as C or Pascal are good for mathematically intensive computation; and a high-level symbolic programming language such as LISP or PROLOG is better for logical reasoning and planning. The choice of FORTH was a compromise between a desire to satisfy all robot programming requirements and the integration problems of implementing a control system.

FORTH is both a computer programming language and a philosophy of software development. It opens up all levels to the user with complete and explicit access. It includes an interpreter, a compiler, an assembler, and a multitasking capability, all existing within a highly interactive atmosphere. FORTH breaks away from traditional batch computer programming; instead of a cycle of compiling, linking, loading, executing, editing, compiling, linking, etc., FORTH software development uses small, verifiably correct modules that are incrementally compiled. This iterative style of software development improves programming productivity.

With the increased speed of development, FORTH makes the fine tuning of design easier (6). Because it is so easy to develop a working implementation of a program, results from the prototype can be compared to the design expectations. Depending on the analysis, the design will be reevaluated or further refined. In traditional software projects, the initial prototype is usually the finished product. With robotics applications, the need to fine tune code is imperative.

FORTH has a symbol table, known as a dictionary, that keeps all the variables

and routines, called words, in the system. Newly compiled words are added to the dictionary as combinations of existing words. Because FORTH is written in itself, system modifications to meet a functional requirement, common in a robot control system, are not difficult. FORTH's extensibility allows new control and data structures to be developed to match a particular programming need. This creativity has led to the development of new robot-specific programming constructs, which simplified the software. Although much of the RCS is not strictly FORTH, many of the language's programming philosophies have been maintained or enhanced. RCS adapted the FORTH model to meet the needs of a robot control system. A study of the impact of FORTH on some of the functional specifications that guided the development of RCS will further explain why we selected it.

Real-Time Requirement. An original RCS implementation goal was real-time performance within a cost-effective control system. The hardware consists of a multi-microprocessor system with the different levels of control and support processes residing on multiple boards. The boards operate in parallel and communicate through defined interfaces, including the commands and status that are defined in a common memory map. Actual communication is controlled by an independent process that synchronizes the data exchange between hierarchical levels.

A major functional requirement of RCS is the output of new control signals for the robot in real time. RCS updates to the individual commercial robots vary, but range from a new position every 25 ms (or 40 new poses/second) to a new position every 100 ms. In order to meet the demands of real-time control, the control system was partitioned among these processor boards.

The constraints of real-time performance and multiboard communication had a profound effect on the software requirements. Typically, interprocess communication is carried out through shared data, a process that presents both hardware and software problems. Where to put the shared data, and how a process must perform the read/write handshake must be resolved to ensure proper communication. Exploiting exact knowledge of the absolute addresses for the communication channels simplifies the task.

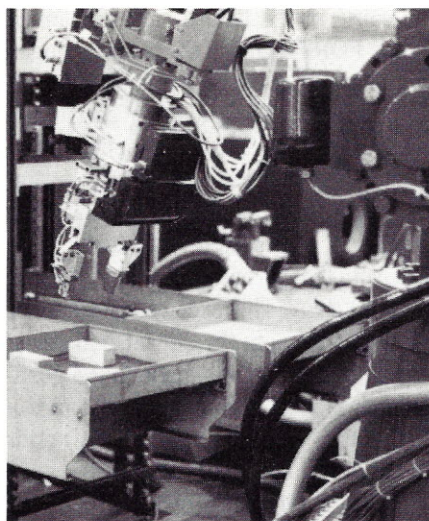


Photo 2. The robotic vision system and the interchangeable grippers are AMRF's additions to the T3 robot.

Understanding system operation is not difficult in FORTH. There is a simple layer of a virtual machine that resides on top of the operating hardware, and the mapping between a logical and a physical address is straightforward. Mixing high-level code with assembly code is also simple. The programming environment provides an on-line assembler for quick and easy machine or hardware access. Interactively testing assembly code further simplifies a hardware-intensive project. Finally, FORTH provides the feel of assembly-level closeness to the machine, yet provides the flexibility of a high-level language.

RCS Reliability. The RCS system was designed to avoid performance degradation due to hardware troubles; failures that require troubleshooting can undermine any unprepared operating system environment. For example, a typical interface to a hardware device has a process awaiting a response. If this polling is embedded in a lower level process, the system performance can come to a standstill.

Because of its dependence on sensor hardware, a robot programming system must be prepared for these problems. RCS incorporates a software design methodology that forbids embedded loops and other types of control structure that would allow a hardware failure to cause the system to hang. Instead, an entire pass through the system is performed each cycle. However, no matter how hard the programmer attempts to anticipate a hardware malfunction, an error status will propagate

up the levels of control and must be handled. Taylor (7) has pointed out that in a robot application such as assembly, only 10 percent of the robot commands are for motion; the majority are for handling I/O and the "anticipated but unpredictable" problems. During robotic software development, there is a strong need for testing and debugging aids that diagnose hardware failure symptoms.

As it turned out, the software requirements of RCS were eased by having the control system on a dedicated, not a general-purpose, machine. RCS is thus not required to provide user protection mechanisms associated with most operating systems. The layers of protection provided by such systems may help with multiuser timesharing, but hinder development under a robot control system in that each layer of protection hides more and more of the operation from the programmer.

RCS Support Tools. Although anyone can "program" a fifth-generation robot, most people don't realize the amount of processing required with even a simple task. Programming a robot requires accounting for so many details of operation that understanding the system supercedes how to program the application. The RCS approach has been that the programming environment is as important as the actual control algorithms. The RCS approach is to provide a system to the user that incorporates as much knowledge as possible about the current state of the robot, and to that end has established a tighter relationship between the system support and the control algorithms.

Understanding complex robot applications demands that a relationship between the system support, including the source code, and the control algorithms be constantly maintained on line. The FORTH on-line global dictionary of the variables and words present in the system provides direct and immediate access to all parts of the system. RCS extends this idea and assigns a variety of modes that depend on defining type with each word in the system. For example, FORTH provides a LOCATE feature that ties a dictionary word to a source disk location. When the user wishes to edit a word, referencing the word with editing intentions fetches the location on the disk, as opposed to remembering an exact location of the word in what file on disk. Further, RCS adds modes of seman-

tic meaning categorized by data type to simplify programming.

Program Correctness and Troubleshooting. In a robotics application, simply proving program correctness is not enough: program correctness deals only with sequential programming, and robotics contains numerous nondeterministic activities. RCS uses a synchronized clock in communications in an attempt to regulate the non-deterministic activities, but even so, intermittent errors caused by unforeseen timing side effects and hardware failures regularly occur in real-time applications and make software testing a tough proposition.

The interactive testing atmosphere of FORTH and RCS simplifies dealing with problematic hardware testing and debugging. The dictionary entry to program a simulated fifth-generation robot to sweep a floor would be as follows:

```
:SWEEP-FLOOR door GOTO
door OPEN broom GET
door CLOSE floor SWEEP;
```

But in robot control the anticipated behavior does not always match the actual behavior. If the robot runs into the door,

the cause of the failure must be pinned down. FORTH and RCS provide single-step capabilities that help pin down an error sequence. For example, each command can be executed independently to monitor robot behavior. Trying again, *door* is pushed onto the stack and then *GOTO* is interpreted separately. The discovery that this works leads to the test of *door OPEN*. This execution causes the robot to crash into the door. Upon study, the determination was made that a push-through type of door was chosen, not a door with a handle. Loading a new door prepares the robot for another try.

This time *SWEEP-FLOOR* causes the robot to slam the door, requiring a fine tune of the system. A simple extension to FORTH, highly used in RCS, allows any lower level word embedded within the code to be reassigned a new execution sequence because of the availability of indirection. Thus, all higher words defined after *CLOSE* will use the original *CLOSE*, but the indirection will provide the location of the new code.

With some tinkering, a new *CLOSE* will cause the robot to close the door quietly. The fine tuning has been achieved with a

minimum of overhead not available in a compiled or downloaded system.

REDUCING COMPLEXITY

Given the complicated nature of robot programming, simply helping with program debugging is akin to handing a pail to the captain of the Titanic. Reducing the software complexity is also required, and one way to achieve this is by reducing the amount of the software through modularization and information hiding. Several programming practices can also help, such as factoring, extensive data and control structure design, and abstract data typing in a class structure architecture.

Factoring. FORTH and RCS promote compact and modular design through expression factoring in which common portions of several different expressions are factored out into a separate expression. Imagine a FORTRAN program containing lengthy formulas. Within three of the formulas, a common expression is calculated each time. Software elegance mandates that the common expression be factored out and represented as a separate expression. The program gains execution speed and software verbosity is reduced. Threaded interpretive languages thrive under this mechanism; not only are mathematical expressions factored, but so are entire algorithms, both small and large.

In FORTH and RCS, a new word can be used to factor recurring larger programming constructs. After a new word extracted from several sources is defined it can act as a building block, and the higher level words can replace the existing code with this word. The FORTH system, as well as application programs, are very compact, and these small modules are easier to verify.

Extensibility. Extensibility allowed the development of many enhancements to accommodate the functional needs of a robot control system. One of the initial extensions was SMACRO, a structured language based on superassembler macros that translates source code directly into assembly. SMACRO was developed to bridge the gap for robot operations that are time-critical, while offering a structured programming control application environment. The SMACRO extension provides FORTH with block-oriented structured language.

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SMACRO allows a user to write structured code within a FORTH programming environment. The programs resemble those written in high-level languages like Pascal, C, or PL/I. These macros generate machine instructions directly executed by the host processor. In general, this object code produced by SMACRO is faster than that for an equivalent structured language program. Further, SMACRO performs direct translation that maintains a simple logical-to-physical addressing layer that is normally lost when executing code of a compiler code generator. Finally, SMACRO maintains FORTH's interactive atmosphere plus allowing FORTH words to mix with the SMACRO machine-generated code.

Most of the control algorithms that are mathematically intensive use SMACRO and its floating-point enhancement, FSMAC. FSMAC provides basic floating-point operators, again executing directly on the math coprocessor chip. In addition, operators important to robot kinematics were added, such as vector operations including vector normal, cross multiply, dot product, and matrix operators.

An example of FSMAC will illustrate FORTH's extension to accommodate new arithmetic operators. The following is a fragment of robot kinematic code:

```
routine CALC-xyz
(Calculate distance from xyz to x'y'z' using
directional unit vector to give scaling
direction back down the arm.)
pose {dx dy dz} .V*S. yr .V=>. dx'
pose {xyz} .V-.dx' .V=>. x'
end-routine
```

The first line contains the $.V*S.$, or vector times scalar binary operator. The vector pose {dx dy dz} represents the orientation unit vector in the x direction of the robot pose, which is a three-element, contiguous floating-point array. This orientation vector is multiplied by the scalar length, yr, which is a constant representing the distance from the yaw point to the roll point on the robot. The second line contains $.V-$, or vector subtraction. The wrist point vector pose {xyz} is subtracted by the amount of dx to derive the amount of distance down the arm to the wrist plate.

Abstract Data Typing. Sophisticated data structures relating to robotics can be developed in FORTH. Within the realm of robotics, the requirement of an object-

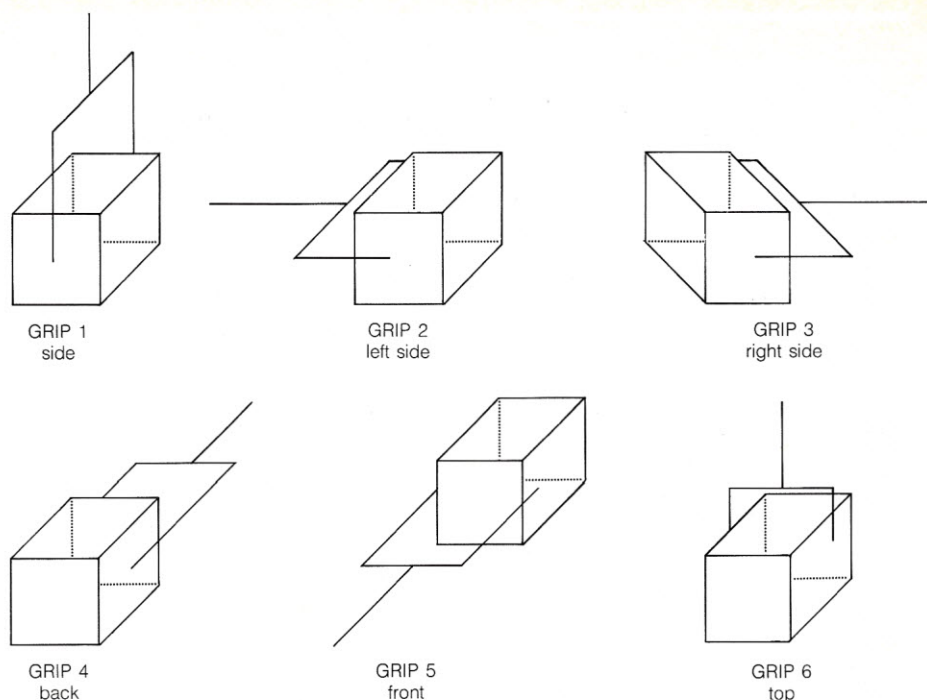


Figure 1. Robotic manipulation of a solid block requires the use of six "grripper rules."

oriented perspective cannot be denied. The work of a pick-and-place robot, for example, is to transfer an object from here to there. Categorizing the data and the functions associated with it is one way to simplify the problem. This type of methodology is known as an object-oriented approach, as opposed to the procedure-oriented approach of languages such as Pascal and FORTRAN.

Using CREATE/DOES>, FORTH can achieve object-oriented structures. For example, assume a robot is involved in a reasoning task about children's spelling blocks. The generic block can be considered an abstract data type with six faces to contain letters. The operations available would be based on the rules in Figure 1.

Reasoning would direct the robot to change the orientation of certain blocks so the letters on their forward-facing sides spelled a word.

In object-oriented structures, the way in which these operations are implemented is less important than the ability to declare an instance of the object and then be able to use the operators included with the object. Each declared instance of a spelling block would contain a different letter on each of its faces. For example, to declare two different blocks:

```
"N" "F" "E" "L" "T" "A"
SPELLING-BLOCK BLK1
```

```
"Q" "B" "S" "P" "K" "R"
SPELLING-BLOCK BLK2
```

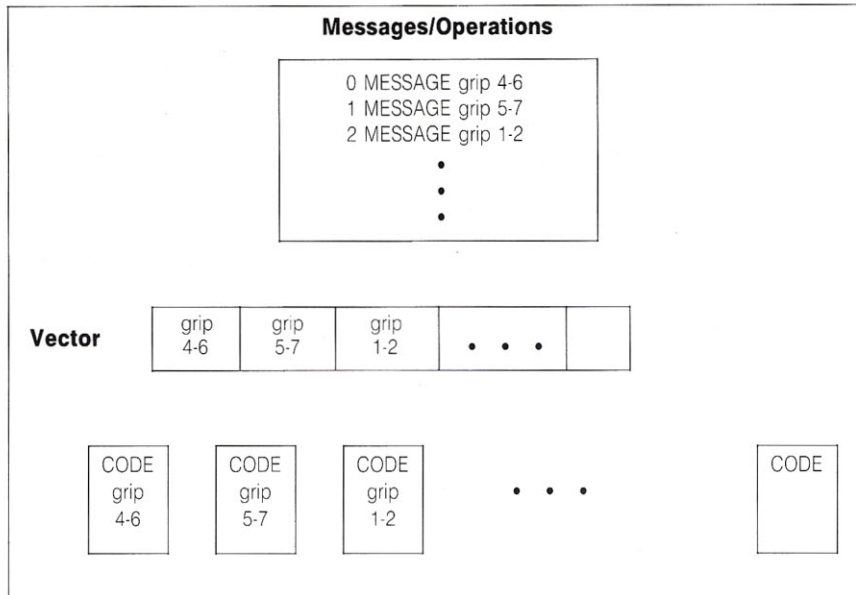
Since both BLK1 and BLK2 share the common operators available with SPELLING-BLOCK, the type of architecture in Diagram 1 (next page) is possible within FORTH.

CONCLUSIONS

The amount of information required for robot control is staggering; thousands, if not hundreds of thousands, of programs, variables, and decision processes, and megabytes of source code, are present in the system. The burden of keeping track of so much data should be transferred from the human brain to the computer. Only with the help of the proper programming environment can sophisticated robot applications be realistically developed.

Robot software development can be easy with FORTH, due to three important features inherent in the language. First and foremost is the interactivity that allows the user to test out routines, do data dumps, or just plain experiment with the system and get immediate responses. Another feature is that routines are usually small and easily verifiable, and tackle only a very specific part of the problem. A routine does not try to handle too much and programs are written hierarchically. FORTH is well suited to top-down design, bottom-up development. The third feature is that

Diagram 1
Class of Spelling Block



FORTH encourages the fine tuning of design through a process of iteration and factoring.

Further information on FORTH is available from the FORTH Interest Group, P.O. Box 8231, San Jose, CA 95155.

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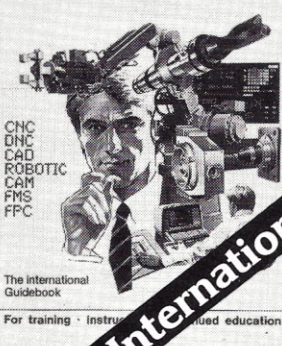
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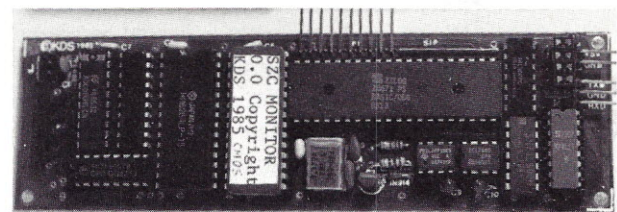
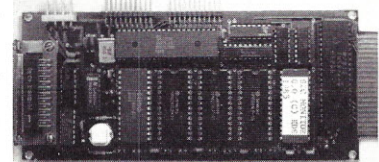
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Mobilizing a Robotic Arm for IC Production

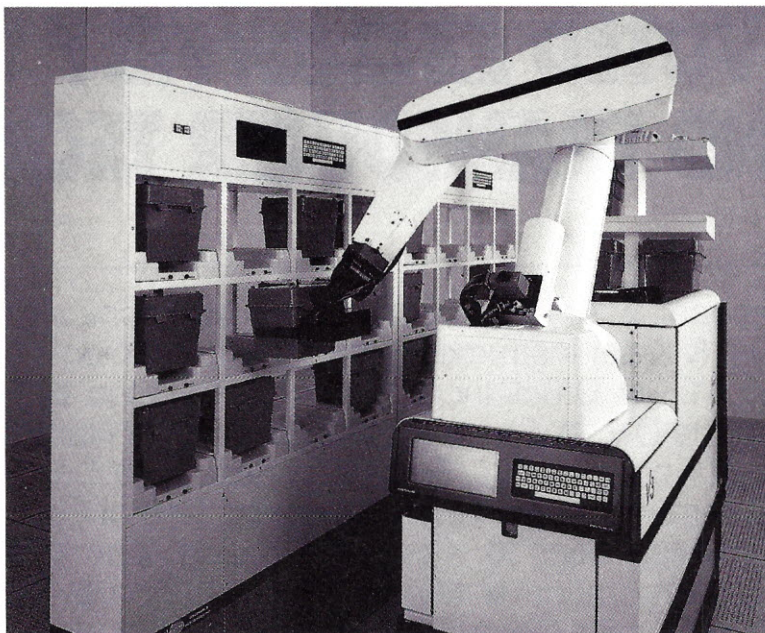
Robert M. Bain

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A major drive is currently under way within the semiconductor industry to optimize yields and product performance in a highly competitive market. Many market leaders have been the innovators in robotic automation, and part of their motivation to implement this automation is a result of the general technological progression in IC production and the geometries of the higher complexity devices. The new megabit memory chips and complex microprocessors require microscopic semiconductor devices and submicron current-carrying circuits that demand

extremely clean environments and precise processing conditions. It was previously acceptable for clean rooms in semiconductor production to allow up to 100 0.5 micron particles per cubic foot of air; in the production of these new devices, the current definition of a World Class 1 environment allows only one 0.3 micron or larger particle per cubic foot of air.

Contamination is a serious problem in semiconductor production because human workers generate significant particulates despite all available precautions. Even with proper clean room suits covering the body, feet, hands, and head, and shielding the face, people still give off tens of thousands of particles per minute. It is conceivable



The V3 mobile robot consists of a carriage, a six-axis robotic arm to which seventh degree of freedom has been added via a rotating "waist," and end effector, and several microprocessors. The "waist" is at the base of the arm.

that a highly efficient air management system and filtration could minimize the exposure of the silicon wafers and processes to that contamination. However, a Class 10 environment requires that the total environment air be exchanged every 5 seconds. The Class 1 room requires that the air be changed *twice every second*. This can become so difficult and expensive that some IC manufacturers wish to identify and implement other approaches.

The automated guided vehicle (AGV) mounted electric robot provides an ideal means of combatting contamination and maximizing cycle time and equipment use. The major current application for such systems is tracking and handling silicon wafer

operations, during which much of the contamination and damage are likely to occur.

Veeco Integrated Automation Inc., a supplier of automated information and material handling systems, was the first to bring out an AGV-based multi-axis robotic system for material handling and process manipulation. One unit, the V3, employs proven technology in an innovative way, using industry standard components for the principal parts of the system. They are:

- A mobile chassis
- A robotic arm and specialized end effector
- Various microprocessors

DESIGN COMPONENTS

The carriage upon which the robotic arm travels is a Litton Automated Systems Group Model 800. Its guidance, movement, and safety interlocks are controlled by a Zilog Z80 microprocessor.

The Unimate Puma Model 560 arm has six axes of movement. A Rockwell 6532 microprocessor controls the operation, tracking, and feedback for each arm joint. The information is fed into a master controller based on a Digital Equipment Corp. LSI 11 microprocessor, which provides the

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executive supervision of the operation of the arm and its individual joints. A sonic sensor array, under the control of an Intel 8031 microprocessor, is interlocked to the movement of the arm so that any intrusion into the work envelope will halt arm movement. A seventh axis of motion is added by a Veeco-designed "waist" that gives the entire arm rotational capability. Waist operation, position, and feedback are controlled by two separate Intel 8031 microprocessors; one controls the actual movement of the waist, while the other monitors its positional characteristics and alignment. Maintaining the arm's positional accuracy requires that the waist have the same precise movements and positional feedback as the arm itself. Power to the arm is supplied by six 12 V batteries. Angling the arm greatly extends the reach and work envelope for both arm and carrier vehicle. While there is ongoing discussion in many industries, including semiconductor manufacturing, about standardizing material I/O stations or ports to bring about uniformity of different vendors' processing equipment, no standards have been completely defined, accepted, or im-

plemented. It was therefore desirable to build the arm with the maximum flexibility and reach possible. Angling made it possible to extend the vertical plane's depth reach at the last wrist joint by 12 in. The height of its reach is from 18 to 82 in. The actual reach of the arm can be extended, depending on the design of the end effector.

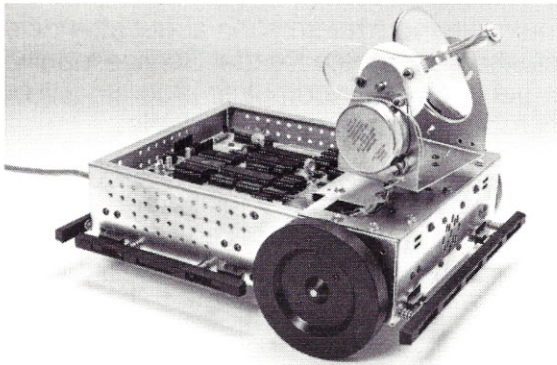
The rotational waist includes 45-degree fixed and pinned registration points that give the arm a wide horizontal work envelope. The arm can be positioned over processing equipment during load/unload operations and then moved over the system's center line for safety during vehicle travel. The waist position and vehicle travel motors are interlocked to permit vehicular movement only when the arm is correctly positioned over the V3 and away from the aisles on either side of the carrier.

A second important design addition is a Terminal Guidance System (TGS) that allows the arm to recalibrate its position at each stopping point. In general, AGVs do not have enough positional accuracy to allow the highly precise movements and positioning required of a robotic arm in clean room operations. The V3 system can

normally stop within 0.25 in. of a programmed spot. The TGS on the end effector at the wrist carries a compact camera and microprocessor control. The camera is a solid-state, charge-coupled device for image recognition.

The AGVs are powered by four 6 V batteries that give the vehicle motion and guidance. For navigation, ultraviolet light is emitted from a lamp to a painted stripe pathway on the floor. UV sensors convert the reflected energy into electrical signals that control the servo motors that keep the vehicle on course. Using fluorescent stripes instead of buried wires permits fast, easy changes in and additions to vehicle routing, and also eliminates the need for physical changes in the flooring. The vehicle also incorporates two additional Intel 8031 microprocessors separately running the module controller that incorporates the bar code readers and presence detectors in each of its material storage bins. One 8031 also controls the operator interface that allows the operator to change the vehicle's instructions and duty list. The entire V3 vehicle operation and its various microprocessors are supervised by an Intel 8086, which governs the execution and

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monitoring of the carrier's individual components.

SYSTEM OPERATION

When the V3 approaches a work station (see photo), it stops at a bar code on the floor for proper alignment to access the station. The arm then positions the camera to look down at a target placed horizontally on the equipment surface. The target is a line array that provides two-dimensional alignment specifications silk-screened on a piece of plastic or metal and coated for protection. With the target as a reference point, the TGS measures the vehicle's position in relation to the target. This allows the microprocessor to generate data concerning the alignment error of vehicle and arm relative to the processing equipment. The information is then used to adjust the robot's operating program to compensate for any inaccuracy in the vehicle's stopped position. The TGS can compensate for inaccuracies as great as 1 in. After alignment, the positional repeatability of the arm is returned to its normal 0.020 in. relative to the processing machine's load/unload platform.

Integral to the V3 horizontal work surface is an automatic box opener. This mechanism securely holds a box or other item while the robot's end effector loosens the clasp. A separate lid opener then lifts the box lid to allow access to its contents inside. The procedure is reversed to load and close the box. These activities are controlled by the vehicle's microprocessors.

The V3 uses a broadcast infrared light system to communicate up-to-the-second information about lot tracking and vehicle position, and to receive activity instructions. Identical transceivers are used on the vehicle and the ceiling or walls of the production facility to provide two-way communication between the systems control and the vehicle. The transceivers are connected directly into the work in progress stations, which provide an Ethernet link to the main system control computer. With multiplexed communication, a Veeco system can have up to 256 vehicles operating in a given facility at the same time. Vehicle routing, scheduling, and collision avoidance are all controlled by the system's proprietary operating software. The system control also provides the routine and periodic reporting and requests for addi-

tional instructions back to the host CAM system.

CONCLUSIONS

An initial application of the V3 led to a reduction in particulates from 20,000 generated per minute to fewer than 10. Particulates from the robotic arm were channelled through the vehicle and emitted about 2 in. from the floor. The particulate reduction was achieved through design enhancements, as well as by an overall evacuation of individual joints and of the entire assembly. An innovative combination of reliable, field-proven components can provide an integrated approach to clean room operations that can be implemented in a modular fashion as production requirements change and grow.

Robert M. Bain is Director of Marketing at Veeco Integrated Automation Inc.

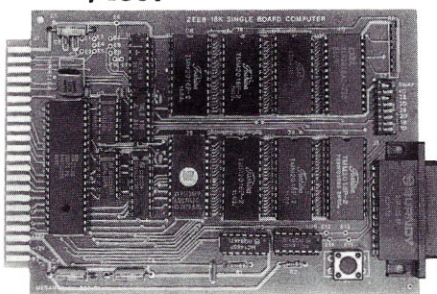
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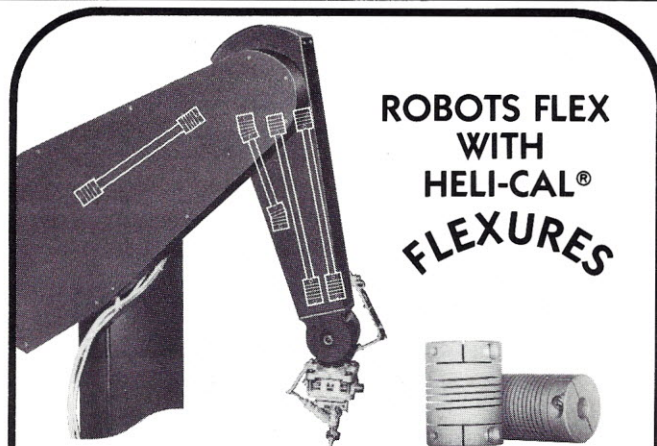
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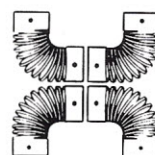
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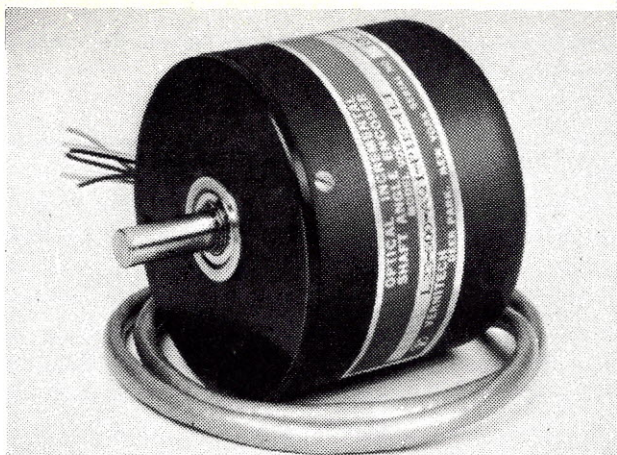
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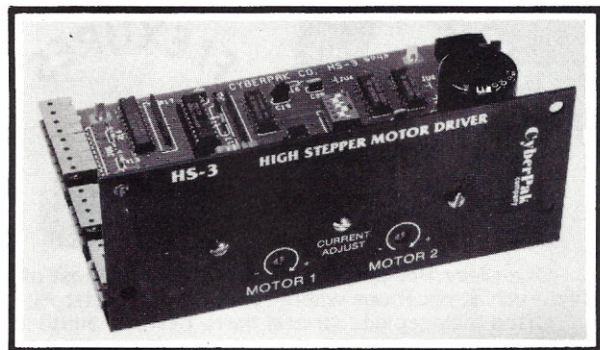


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In The Robotics Age™

Edited by Stephanie vL Henkel

CORPORATE NEWS

► **Joseph F. Engelberger**, the "Father of Industrial Robotics" and founder and first president of Unimation Inc., has formed a new company, **Transitions Research Corp.** The firm will provide consulting and technology development services in the areas of navigation systems and mobile applications; it has already received a contract to develop an autonomous robot for commercial floor cleaning.

► **Gould Inc.** has announced two acquisitions: **PSC, Inc.** and the **Vision Systems Division of Automation Intelligence, Inc.** PSC is a computer and electronics systems engineering firm with over 150 engineers and scientists. It will be integrated into Gould's Defense Systems Business Section. Automation Intelligence President and CEO Ted Fluchardt said the divestiture would allow his firm to focus entirely on CIM software, products, systems, and service.

► Seven more companies have announced support for **Intel Corp.'s BITBUS™**, bringing to 18 the number of manufacturers that have adopted the architecture in products for the OEM market. The new addi-

tions are Analog Devices, DEC, GMF Robotics, Honeywell, Toshiba, Varian Associates, and Westinghouse. The BITBUS is a serial I/O expansion bus designed to provide connections between microcontrollers in factories and labs.

► **Odetics, Inc.** has formed an **Advanced Intelligent Machines Division** that will serve as the strategic focal point of the entire corporation. The new division will concentrate on developing various types of robotic mobile platforms, manipulators, vision systems, and embedded computers. The firm's initial venture into mobile robots was ODEX, a six-legged "functionoid" unveiled in 1983.

► **Artel Communications Corporation** has announced that **Computervision** will support Artel's fiber-optic communication systems as part of its standard CAD/CAM maintenance program. Customers will deal directly with Computervision for service in those areas. Artel has installed nearly all the Computervision Insta-view-compatible fiber-optic systems in current use.

PEOPLE

► **Richard (Rick) Clendenen** sales. His previous work was for the Modicon Division of Gould and for Static Controls.

In The Robotics Age™

► **Donald J. Kramer** has been appointed chairman of the board of **Maxitron Corporation**. He is a partner of TA Associates, a Boston-based venture capital firm, and has been associated with Hendrix Electronics and Modicon. He joined Gould in 1977 when it bought Modicon.

► **Litton** has named **Robert L. Douglas** president of Litton Engineered Systems, a division of the firm's Industrial Automation Systems Group. Douglas was formerly VP and general manager of Gilman Engineering and Manufacturing.

► **Richard A. Myers** has been named VP of marketing and sales by **RWT Corporation**. He has worked for White Consolidated Industries and McDonnell Douglas.

► **Telemecanique** has appointed **Christian Thomas** president and CEO. Thomas, a 16-year veteran of the company, was most recently technical manager of Telemeca-

nique's manufacturing division for power controls.

► **Westinghouse** has appointed **Ralph E. Recka** to the new position of VP and manager of the automotive industry automation programs. Recka has held a number of previous positions with the firm.

► **Steven Marco (Steve Marco) Apostolides** has been appointed executive VP and COO by **Itran™ Corporation**. Before joining the firm in 1985, Marco worked for General Electric Robotics & Vision Systems Dept. and for Thermwood. He has also led his own consulting company, Marcon Inc.

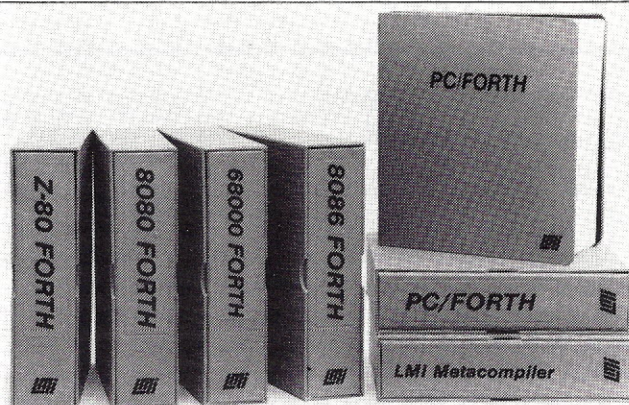
► **Cognition Inc.** has appointed **Stuart A. Bernstein** vice president of sales and company founder, completing the team of 11 Cognition founders led by company president Philippe Villers. Bernstein was previously associated with Control Data.

NEW JOURNAL

Soma: Engineering for the Human Body is a quarterly journal covering engineering in medicine, sports, physiology, and physical therapy and rehabilitation. Scheduled to appear this spring, *Soma* will carry reviews of medical and sports devices including robotic aids for the handicapped,

sports equipment design for rehabilitation, artificial organs, and CAD of prosthetics. The journal is a joint publishing venture between the American Society of Mechanical Engineers and Williams & Wilkins, Journal Division of Waverly Press, Inc. ASME will be responsible for editorial content.

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New Products

Automated System Offers "Hands-Off" Wafer Transfer/Loading

An integral part of the furnace load station, TYLAN's automated wafer transfer and loading system is designed for robotic movement of quartz cassettes. The system can transfer wafers from plastic cassettes to quartz cassettes, which are then put onto a noncontact loader. After thermal processing the procedure is automatically reversed. The entire operation is completely enclosed within a laminar flow load station. The system is composed of a four-axis, closed-loop, programmable Cartesian robot that interfaces with an optional batch or single wafer transfer machine. Between operations, cassettes are stored at staging areas within the load station at each tube level. The system is rated for class 100 environments.

For more information, contact: Allan B. Freeman, Marketing Services Administrator, TYLAN, 23301 S. Wilmington Ave., Carson, CA 90745, telephone (213) 518-3610.

Circle 100

Compiler Converts Logic Inputs into Design Data at Near Real-Time Speeds

ALDEC's SLAVTM (Schematic Logic Analyzer and Verifier) provides automatic logic design and testing by using a special purpose, very fast compiler that converts logic inputs into design data at near real-time speeds. Inputs can be obtained from a mouse used to draw lines on the PC monitor or from the insertion of netlists of logic equations. Possible end results include an automatically configured discrete logic system consisting of standard 5400/7400 logic gates; logic implementation that employs a microprocessor system that has the Intel 8051/8751, Motorola 6804/6805, or National Semiconductor COPS; and automatically generated logic systems employing gate arrays or PALs. The system can use either one or two CRT monitors. If two screens are used, a color monitor displays the logic schematic and a monochrome monitor presents the timing signals. In a one-screen implementation, the user toggles between the schematic and timing displays.

For more information, contact: ALDEC, 3525 Old Conejo Rd. #111, Newbury Park, CA 91320, telephone (805) 499-6867. Circle 101

LISP Package Allows AI Development on a PC

Microsoft LISP is designed to provide the PC user with a fully integrated LISP programming environment for the development of sophisticated artificial intelligence software systems. Version 5.1 includes, among other features, over 400 Common LISP functions, macros, special forms, and control variables; a trace and debugging facility; an on-line LISP tutorial system; exact integer arithmetic, providing thousands of digits of accuracy; adjustable precision rational/floating-point arithmetic; a library for irrational and transcendental arithmetic functions; DEFMACRO for defining macros with destructuring of the argument list; and machine language interface support.

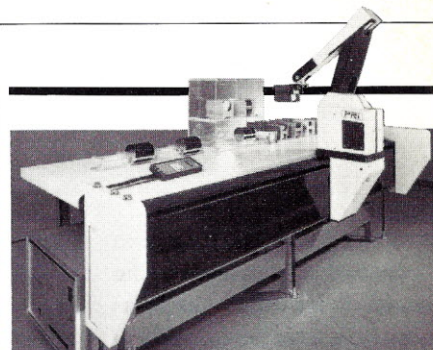
For more information, contact: Sandra M. Jacobson, Microsoft Corporation, 10700 Northup Way, Box 97200, Bellevue, WA 98009, telephone (206) 828-8080. Circle 102

Upgraded Software Is Designed for Industrial Robot

Seiko is offering new, upgraded software for its D-TRAN line of industrial robots. DARL II (D-TRAN Assembly Robot Language), compatible with all existing Seiko D-TRAN units, is supported by a new CPU board that is also compatible with existing Seiko controllers. The software features 64K of memory, seven 8K banks for programming, and one 8K bank for translation points, variables, and PALLETS and FRAMES subroutines.

DARL II separates individual coordinates in a translation point, which allows the programmer to perform logic and mathematical computations on a coordinate. In the FRAMES subroutine, translation points can be taught and stored relative to a specified frame, yet the T-point coordinates can be displayed relative to the current frame. This allows T-points to be used in various frames or to be used in subsequent program modifications without teaching the same point. Each axis also can be independently adjusted for speed.

For more information, contact: Applications Engineering Dept., Seiko Instruments U.S.A., Inc., 2990 W. Lomita Blvd., Torrance, CA 90505, telephone (213) 530-8777. Circle 103



Clean Room Robot Saves on Aisle Space

A new family of robots, Model PRI-2000, is designed for use in clean rooms and other contaminant-free environments. The robot arm uses a unique track system that allows it to be attached to the side of a bench without sacrificing aisle space. The track is available in 1-ft increments up to 20 ft. The arm and controller are based on the PRI-1000, currently used in class 10 to 100 clean rooms in the semiconductor industry. The robot is available in three- to five-axis models and is particularly suitable for operations in semiconductor wafer and cassette transfers, magnetic disk handling, chemical analytical lab material handling, and, with an optional flexible cover, for handling materials in corrosive baths. It can handle loads to 15 lb. with speeds to 15 in./sec. and repeatability of 0.004 in.

For more information, contact: Precision Robots, Inc., 6 Cummings Park, Woburn, MA 01801, telephone (617) 938-1338. Circle 104

Programmer's Tool Translates dBASE Applications to C

The dBx Translator system, developed by Desktop A.I., moves dBASE programs into the C language. It allows the conversion of dBASE applications for speed and improved performance or for multiuser and network applications. The system includes a language translator for processing dBASE source and a run-time library tool box to replace the dBASE screen handler. The converted dBASE code becomes a functional and controllable C program that gives an application developer control over the product and release from the problems and royalty costs of dBASE.

For more information, contact: Jacqueline Pugsley, Desktop A.I., 1720 Post Road East, Westport, CT 06880, telephone (203) 255-3400. Circle 105

New Products

Symbolic Computation Speeds High-Tech Design

A new feature of SMP version 1.5 from Inference Corporation is the generation of error-free FORTRAN source code for SMP-developed problem solutions and algorithms. The code can be separately compiled and incorporated into other FORTRAN programs for further calculations outside the SMP environment. Version 1.5 also provides enhanced graphics capabilities for both low- and high-resolution graphics. SMP supplies the user with easily analyzed displays of curves and surfaces. The engineer can work with design formulas in customary mathematical terminology and concentrate directly on overall design goals rather than distracting details. Applications include electronics, robotics, nuclear physics, chemistry, optics, and geophysics.

For more information, contact: SMP Division of Inference Corporation, 5300 W. Century Blvd., Los Angeles, CA 90045, telephone (213) 417-7997. Circle 106

CIM Software Runs on MicroVAX II

I. P. Sharp's PROMIS (PROcess Management and Information System) automation software can now be run on Digital Equipment Corporation (DEC) MicroVAX II hardware. The software is a directive, real-time shop floor control system with extensive planning, tracking, reporting, and engineering analysis capabilities.

PROMIS instructs workers precisely what to do at each work station. At the same time, it checks input data for validity. A minimum MicroVAX II configuration capable of control-

ling a fab facility would include the computer, with five megabytes of main memory, plus two DEC RA-81 disk drives. In its fullest configuration, a MicroVAX II with nine megabytes of main memory and four RA-81 disk drives could support as many as 32 directly connected pieces of production equipment or terminals. In larger facilities, PROMIS typically runs on one or more full size VAX minicomputers and can support over 100 terminals, robots, and automated machines.

For more information, contact: Ted Levine, I.P. Sharp Associates, 4699 Old Ironsides Dr., Suite 300, Santa Clara, CA 95054, telephone (408) 748-9822. Circle 107

Database Includes Specs on 450 Robots

The Version 11 robot database from Robot Analysis Associates, Inc. features manufacturer certified specifications on over 450 industrial robots, including some models to be

introduced at Robots 10. The software's 60 search fields permit additions to the user who wishes to conduct price, performance, and other robot evaluations.

For more information, contact: Robot Analysis Associates, Inc., Box 1507, Pinehurst, NC 28374, telephone (919) 295-5795. Circle 108

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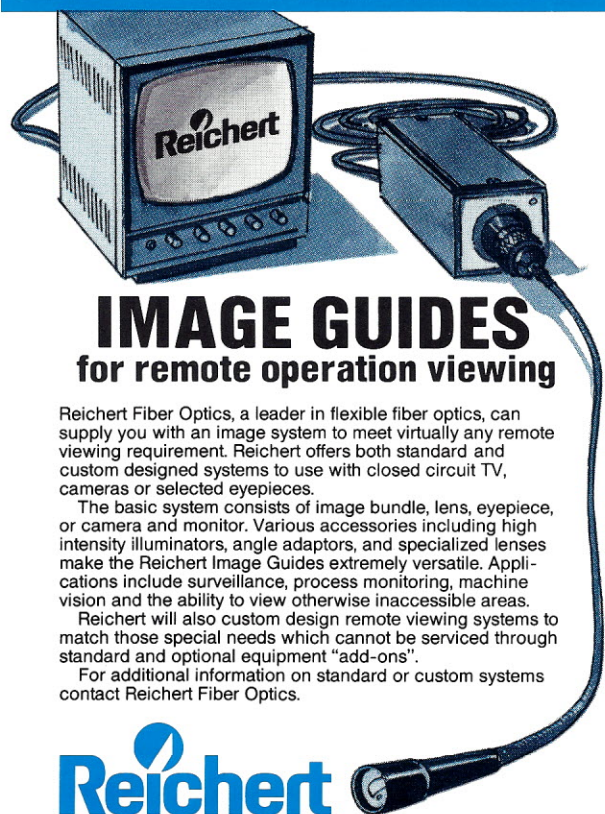


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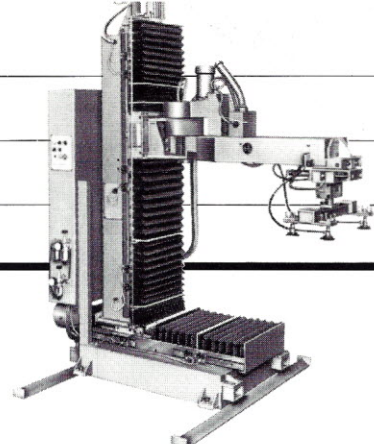
For more information, contact: Colleen Clarke, Ziatech Corporation, 3433 Roberto Court, San Luis Obispo, CA 93401, telephone (805) 541-0488.

Circle 109

Software Package Provides Complete Programming Environment

MasterFORTH for CP/M 68000 computers, offered by MicroMotion, is a complete programming environment that includes a 68000 macroassembler and full interface to CP/M 68K. Relocatable utilities and transient definitions make it possible to run substantial software packages. The string package, screen editor, and resident debugger are standard features. The optional target compiler produces optimized application programs for virtually any programming environment. MasterFORTH exactly matches the FORTH-83 standard dialect described in *Mastering FORTH* (Brady, 1984), which is included. Floating-point and relocater extensions are available. MasterFORTH is also available for the Macintosh, IBM PC family, Apple II family, Commodore 64, and CP/M Z-80.

For more information, contact: MicroMotion, 8726 S. Sepulveda Blvd. #A171, Los Angeles, CA 90045, telephone (213) 821-4340. Circle 110



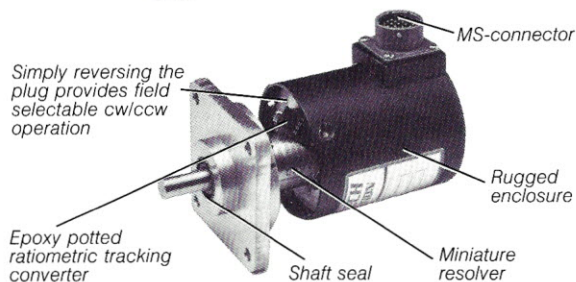
Industrial Robot Uses Special Swing Arm

The PRM-II, offered by Continental MDM Inc., is equipped with a special swing arm that provides additional reach capacity for intricate lift, load, and remove sequences. The arm can travel in a semicircle with a 41 in. radius. It can serve machine tools, or assembly stations for metal products. The robot weighs 1874 lb., with body travel from 9 in. to 61 in. Powered by three fractional hp motors, it can lift up to an 88-lb. workpiece. The machine controls will accept program inputs at the machine, and will store programs for future use when required.

For more information, contact: M.A. Jarman, Continental MDM Inc., PO Box 299, Aurora, IN 47001.

Circle 111

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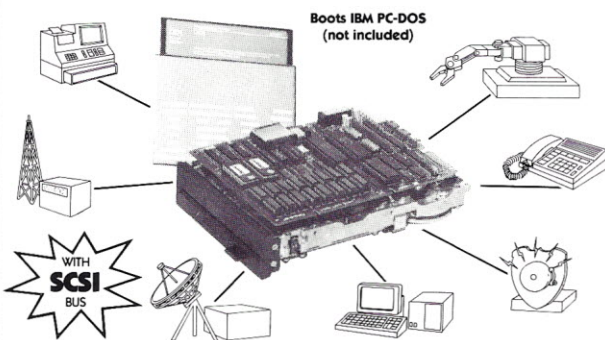
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5/86 RE

Why robot vision doesn't have to slow a robot down.

Most robot vision systems simply aren't good communicators. They load a robot down with more data than it can handle... and transmit that data over slow serial or I/O ports. So while they might "see" in real time, they can't make the robot react in real time.

AdeptVision™ can... and does.

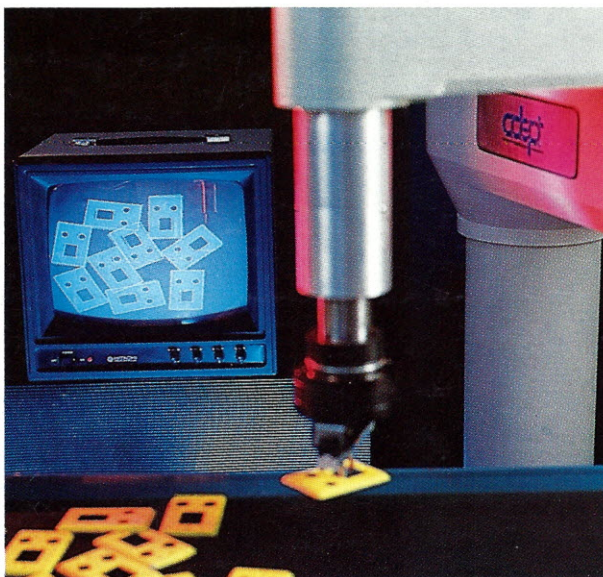
Real time vision, real time reaction.

AdeptVision communicates with the robot controller quickly because it communicates directly... in the same language... without any of the integrating hardware and software that slows other systems down and drives installation costs up.

In other words, AdeptVision comes fully integrated with the Adept robot system, and the result is sheer speed. In both its area and moving line versions, AdeptVision identifies and locates up to six parts per second — and communicates the information fast enough to guide the robot's path in real time.

Simplicity plus brainpower.

Most vision systems require special software for each part they handle. And most vision companies don't tell you



that. This can burn up several man-months of an expensive programmer's time and delay your start-up significantly.

AdeptVision requires no part-specific software. It's ready to go the day you install it and requires only about 15 minutes of training per part.

What's more, because AdeptVision identifies significant part features instead

of the entire part area, it accomplishes more with less raw data. And then turns it into real time robot guidance information with powerful 68000 processors.

Touching and overlapping parts.

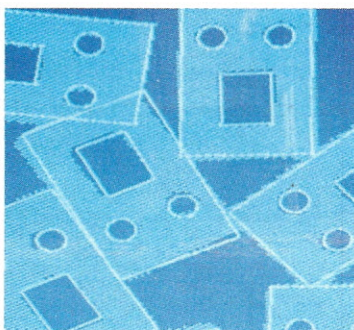
Most vision systems can't identify parts the way they're presented in real life: randomly oriented, touching, or even overlapping. AdeptVision can, because its unique algorithms work with part features instead of areas.

This flexible parts presentation ability can save you a fortune in hard tooling costs

now... and later on when you change product mix or design.

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We'd like to show you AdeptVision in action... at an Adept-equipped systems integrator near you. Just give us a call, and we'll make the arrangements. In the meantime, we'll mail you all the details. Just contact Adept Technology, Inc., 1212 Bordeaux Drive, Sunnyvale, California 94089. Phone: (408) 747-0111. TELEX: 171942.



AdeptVision™ quickly identifies randomly oriented, touching, or overlapping parts.



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Robots that work.